Fraunhofer EMI

Fraunhofer Institute for High-Speed Dynamics, Ernst Mach Institute, EMI

Research for a Safe Future.

Annual Report 2023/2024

Research for a Safe Future.

Annual Report 2023/2024

Developing tomorrow's security technologies today

Dear reader,

two major processes shaped Fraunhofer EMI in the past year. Intrinsically, it was the overdue strategy process for the institute and extrinsically the financial constraints imposed on us by the considerable funding cuts in the "Research and Technology" budget of the Federal Ministry of Defense (BMVg).

Strategy process: New focus topics for the institute

The strategy process has once again impressively demonstrated to us what is essential, what is feasible and what is necessary for the future viability of the institute. In a departure from previous strategy rounds, we no longer focused solely on business areas and core competencies, but instead took a central guiding principle into account: *Identify, develop and market scientific challenges with innovation-promoting potential in EMI's research fields.* This approach led directly to the designation of nine so-called focus topics. These topics, derived directly from the guiding principle, were evaluated using SWOT, market and future analyses and ultimately reduced to six. The remaining topics are now analyzed in regular strategy rounds with regard to their resource requirements and given special support. In particular, these are:

- Highly-dynamic X-ray
- Battery safety
- Laser-matter interaction
- Resilience engineering
- Satellite-based data analysis
- Realistic traffic predictions

This annual report presents the first three topics and their current status at EMI. In the next report, we will also shed light on the other three topics.

Budget challenges successfully overcome

The second major challenge for the institute was to compensate for a deficit of € 5.5 million that was spontaneously announced at the beginning of January 2023.

The loss of funding from the BMVg had to be countered with short, medium and long-term measures. These included reducing the number of new hires and contract extensions as well as the creation of dual-use approaches and, of course, maximum acquisition from industry and public funding bodies. The many years of successful cooperation with both potential sources ultimately led to the crisis being overcome. The extraordinary commitment of the employees and the knowledge of the special value of EMI research for protection and impact in the BMVg area saved us from worse. This was the only way we were able to conclude the past year with a highly successful result, not only in terms of research planning but also commercially.

Milestone: world's first X-ray crash with 1000 images per second

Almost incidentally, the world's first X-ray-instrumented full vehicle crash was carried out at EMI in cooperation with Mercedes-Benz during this reporting period. A competence that we have developed over many years, which required a great deal of engineering, logistics and not least safety expertise and which is now ready for the market. Not only for full vehicles, but also for components and speeds of all kinds. As director of the institute, I am extremely proud of the people I have entrusted with this project!

I would also like to mention two logical links to the dynamic X-ray crash because they are at least as promising:

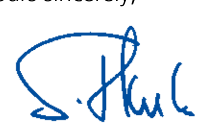
– Our TEVLIB battery testing center, which has now also become operational and in which charged lithium-ion batteries can be tested for abuse loads. And in which highly dynamic X-ray methods are also used.

– Grey box processing is a completely new concept for the utilization of elaborately generated experimental data for validation purposes. This new form of completing discretely available experimental data and the precise determination of deviations in corresponding models for numerical simulation will make development processes more efficient and predictive in the future.

These and many other EMI topics can be found in this annual report.

I would like to thank all our partners, customers and colleagues from science, business and politics for the trust they have consistently placed in us. I hope you enjoy reading this report and find it both informative and inspiring!

Yours sincerely,

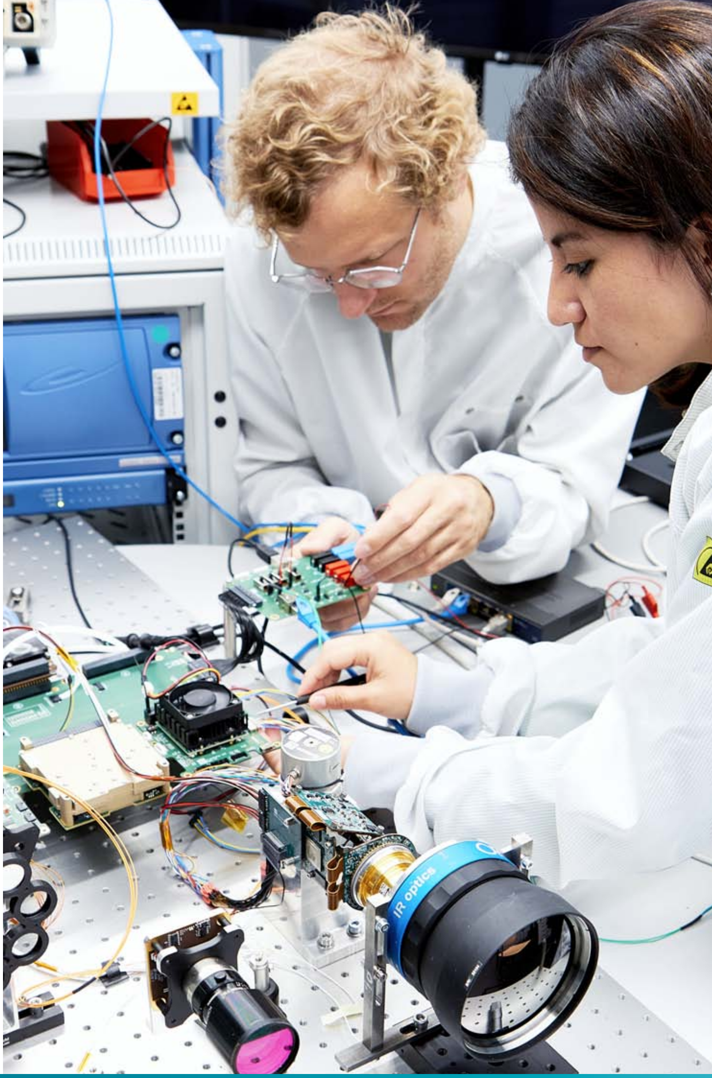


Prof. Dr.-Ing. habil. Stefan Hiermaier
Director Fraunhofer Institute for High-Speed Dynamics,
Ernst Mach Institute, EMI

Cover photo: Mercedes-Benz Group AG, Foreword photo: Fraunhofer EMI

Fraunhofer EMI Annual Report 23/24

Crash test with linear accelerator: method developed at Fraunhofer EMI.



Cover
Fraunhofer EMI and Mercedes-Benz have carried out the world's first X-ray crash at 1000 frames per second.

→ Read more from page 58.

Fraunhofer President Prof. Dr. Hanselka finds out about the ERNST nanosatellite as part of his dialog tour. The launch is scheduled for the summer.

→ P.71

Focus topics

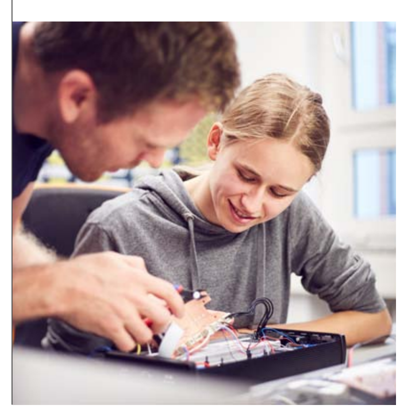
The institute has identified six focus topics in the 2023 strategy process. The first three are presented here.

Innovative recycling process for fiber composites (top: new; bottom: after recycling).

Business units

Increasing safety: How can lithium-ion batteries be made safer?

Profile of the institute



Photos: Mercedes-Benz Group AG, Fraunhofer EMI (5)

The institute


Location Freiburg


Location Efringen-Kirchen


Location Kandern

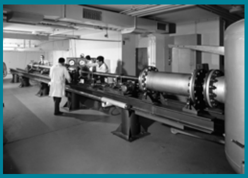
Fraunhofer EMI was founded in 1959. Its mission is to deliver the most precise results and to develop the most outstanding technologies.

The focus is on making everything that happens quickly representable and measurable. Fraunhofer EMI researches collisions, explosions and the associated safety concepts for a disaster-proof and resilient infrastructure.

1959
Foundation of the institute

Fraunhofer EMI emerges from the Institute for Applied Physics at the University of Freiburg, founded in 1956.

It was incorporated into the Fraunhofer-Gesellschaft as the 6th institute.



Cold War:
Research for the Bundeswehr and its allies

In the first decades, the focus is on ballistic and fluid mechanics research.

To this end, the institute develops world-leading research approaches.

Further locations in Efringen-Kirchen and Kandern

The original quarries in Wintersweiler and Holzen are transformed into independent sites with research infrastructure.

Globally unique infrastructure in the field of high-speed dynamics

Fraunhofer EMI quickly establishes its reputation as one of the world's leading institutes in the field of high-speed dynamics. Over the years, expertise and technology are continuously developed.

395

Employees

34.4

million euros total budget

3

Locations

Business units

Defense

Security & Resilience

Automotive

Space

Aviation

Associations

VVS Defense, prevention and Security

MATERIALS Materials, components

Coordinating institute of the Sustainability Center Freiburg

Alliances

Aviation & Space

Batteries

Lightweight

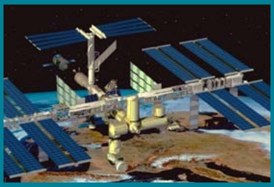
Simulation

Construction

Competence field Additive Manufacturing

1990s
Opening up to civilian research

After the end of the Cold War, the institute realigns itself. It opens up civilian topics such as security, automotive and structural protection: In 1993, EMI is commissioned to reconstruct the first bomb attack on the World Trade Center.



2000s
Aerospace as new business fields

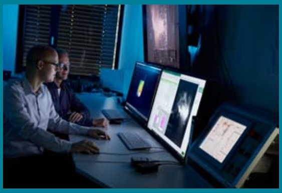
EMI transfers expertise in high-speed dynamics to the fields of aerospace.

For example, EMI conducts an investigation into the impact of meteoroids and space debris on the Columbus module of the ISS space station.

Development of crash tests with X-ray technology

For years, Fraunhofer EMI has been pursuing the goal of X-raying cars during crash tests.

Initially, only 8 X-ray images could be produced. Today, the EMI system produces 1000 X-ray images per second.



Research for a safe future

With its business units of defense, security, automotive, space and aviation, the institute has consistently focused on increasing security in the civil and military sectors.

Photos: Fraunhofer EMI (9), US Department of Justice, ESA

Photo: Mercedes-Benz Group AG

World's first X-ray crash with 1000 images per second

"A milestone in the development tools of the future," says Markus Schäfer, CTO of Mercedes-Benz, describing the X-ray crash. Fraunhofer EMI and Mercedes-Benz have carried out the world's first complete vehicle crash with highly dynamic X-rays in a joint project.

You can find out more about the X-ray crash in the "Automotive" chapter.

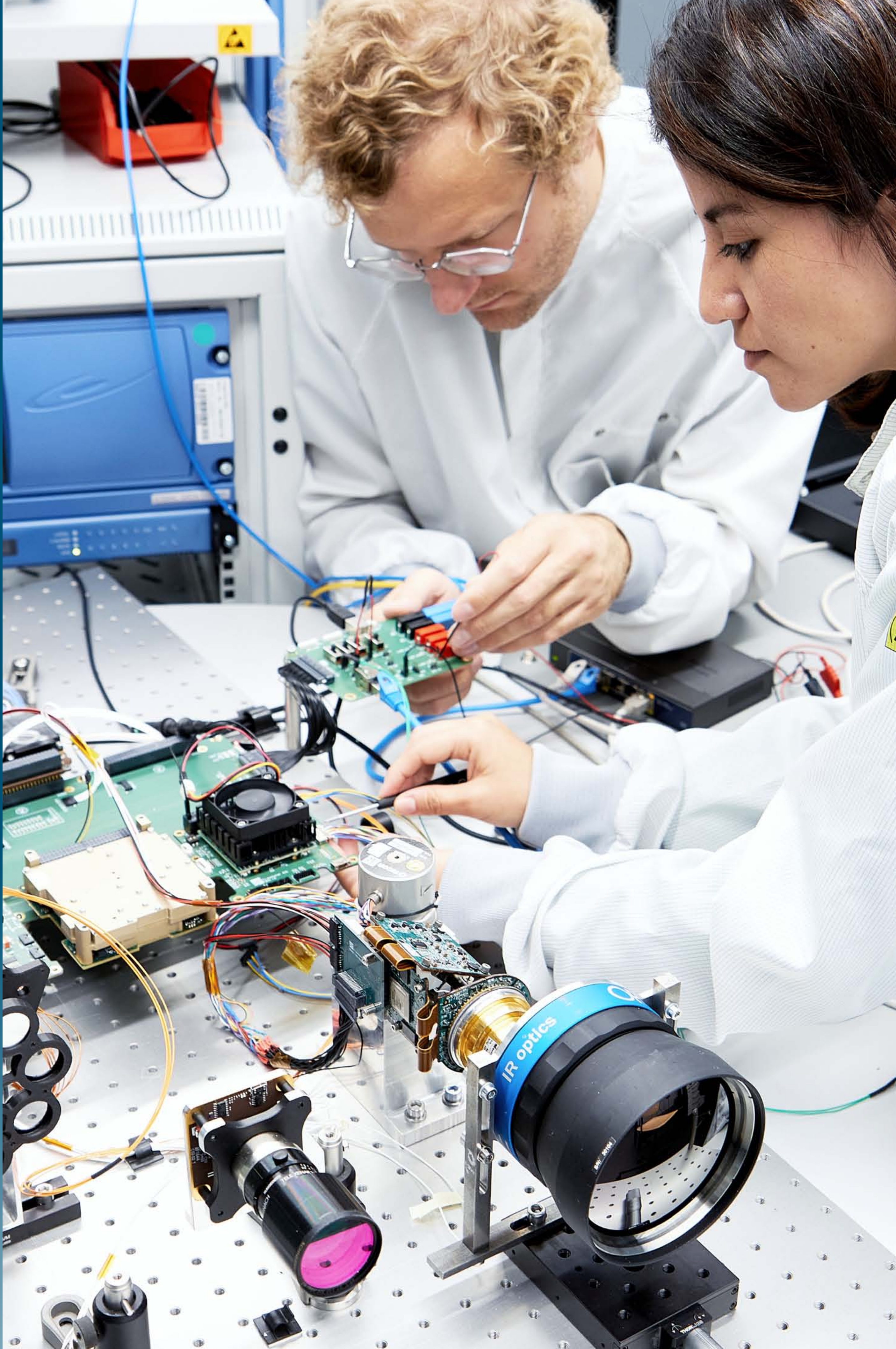

IR optics

Photo: Fraunhofer EMI

Focus topics of the institute

Fraunhofer EMI has updated its institute strategy for the period 2023 to 2027. Six focus topics were defined in a joint strategy process. These topics are particularly promoted by the institute.

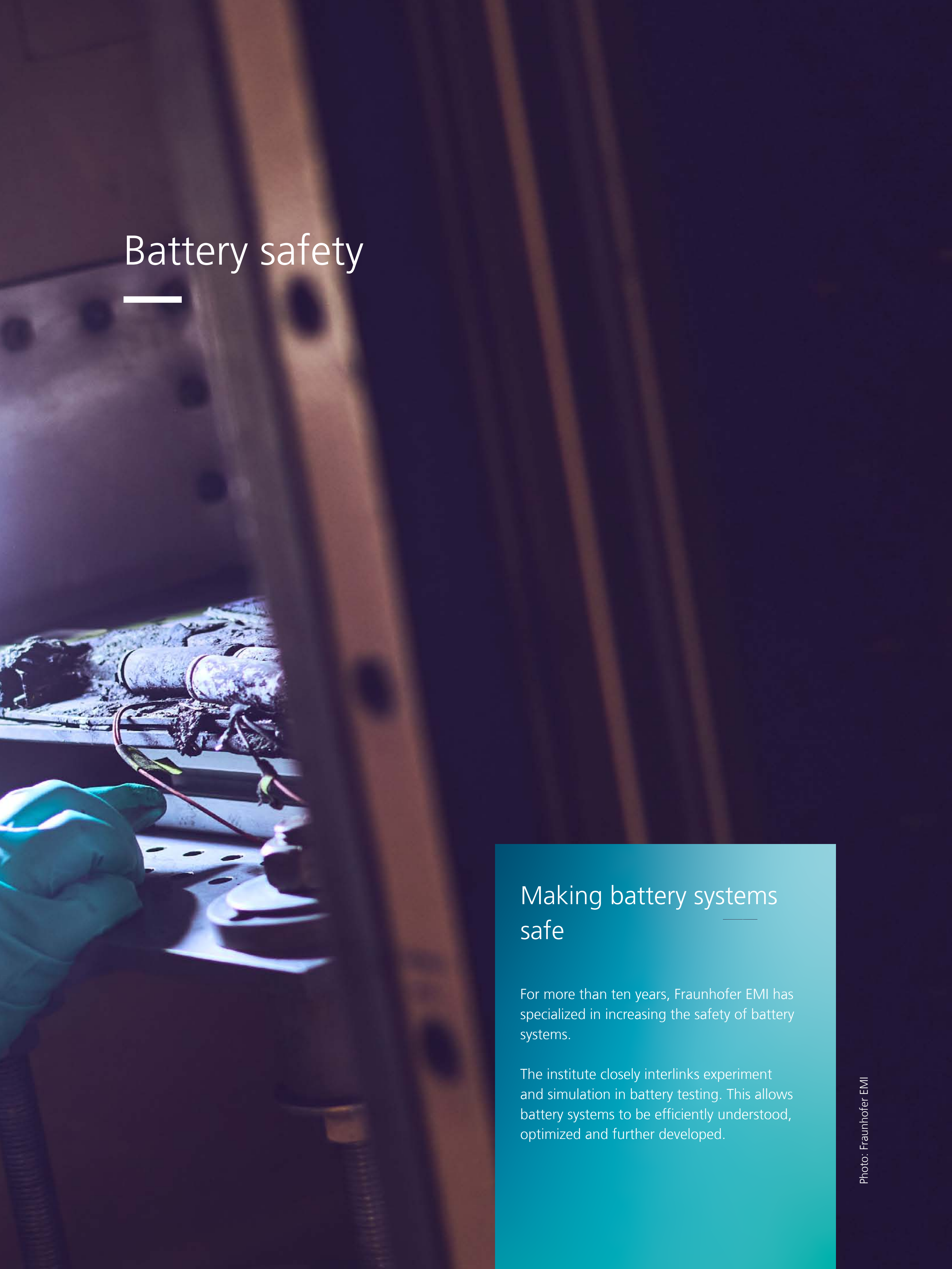
Battery safety	Laser-matter interaction	Highly-dynamic X-ray
Resilience engineering	Satellite-based data analysis	Realistic traffic predictions

This year's annual report presents the first three focus topics. The remaining topics will follow in the next annual report.

← **Satellite-based data collection and analysis**
Work on the ERNST nano-satellite

FOCUS TOPIC Battery safety

Battery safety



Making battery systems safe

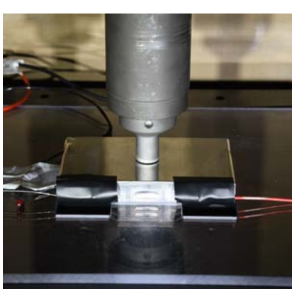
For more than ten years, Fraunhofer EMI has specialized in increasing the safety of battery systems.

The institute closely interlinks experiment and simulation in battery testing. This allows battery systems to be efficiently understood, optimized and further developed.

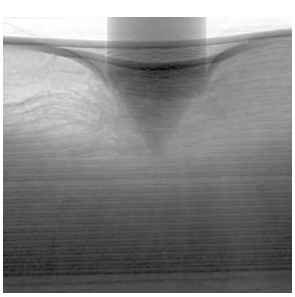
Photo: Fraunhofer EMI

Comprehensive battery tests for a detailed understanding of the system

Fraunhofer EMI offers analysis, evaluation and optimization of safety at the cell, module and overall system levels.
A special research facility has been set up for electric cars. This allows complete vehicle batteries to be tested under abuse conditions.



Mechanical cell characterization
Test of all common designs (prismatic, cylindrical, pouch) against intrusion with different punch geometries. Test series are used to determine the critical forces and intrusion depths that lead to an internal short circuit. In addition, tests can also be carried out at high test speeds with precisely limited intrusion depths, even on charged cells.



In-situ X-ray video
Using high-speed X-ray technology developed in-house, the cell's internal dynamics during thermal runaway can be recorded. Until now, these processes have remained hidden. Thanks to X-ray technology, manufacturers can now develop cells and batteries with greater safety.

Test chamber for destructive battery tests: Extensive measurement technology enables a detailed analysis of the battery behavior during the thermal runaway: e.g. determination of the chamber pressure, the temperature on the cell and the gas volume during venting.

Propagation tests
The institute carries out propagation tests on battery modules and systems in a fire and explosion-proof bunker. For example, the resistance of new housing concepts to internal battery fires and the effectiveness of propagation-inhibiting measures can be evaluated.

Crash tests of modules and HV storage systems
The institute has a battery crash accelerator to assess the crash safety of charged modules and HV storage systems. In conjunction with simulations, battery systems can be comprehensively described and researched.

Photos: Fraunhofer EMI (5)

Simulation and virtual prototypes

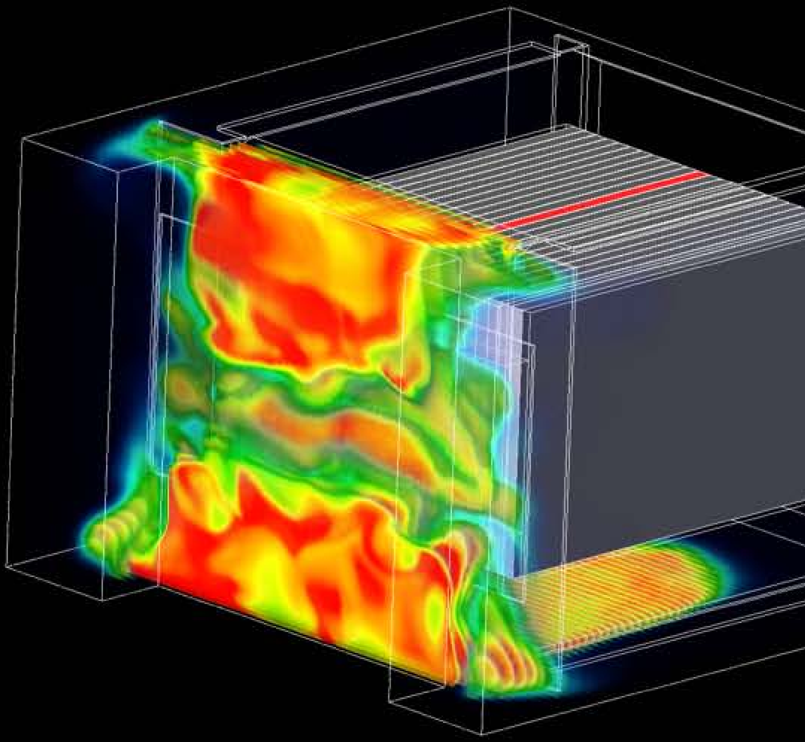
Simulation methods provide detailed insights into the deformation behavior of batteries and the phenomenology of thermal runaway.

Efficient way to a safe battery system
In close conjunction with tests in the battery test center, realistic simulation models are created that optimize battery systems more efficiently and cost-effectively than pure experiments.

Assessment of mechanical deformations
Detailed structural mechanical models realistically depict mechanical deformations of batteries that occur in crashes. This includes individual cells, battery modules and housings.

Flow simulations for thermal runaway
Computational fluid cynamics (CFD) enables enable the simulation of gas propagation and chemical reactions during thermal runaway. The basis for this is profound testing and knowledge of the cell chemistry at hand. Sound modeling of thermal runaway also requires the consideration of the released particles, since they transport a significant portion of the heat.

Effects of thermal runaway
To prevent the spread of thermal runaway, it is important that adjacent components maintain their structural integrity. A comprehensive safety assessment therefore requires not only the simulation of the fire, but also sound modeling of the thermomechanical material behavior of the surrounding structures.



Exemplary flow simulation for the venting of a battery cell in the module
Geometry kindly provided by RCT Power GmbH.

Fields of application

Automotive

Crash safety of electric vehicles, designing batteries against thermal runaway

Aviation

Risk of personal electronic devices in the aircraft cabin,
drone impact on aircraft structures

Stationary storage

Security concepts for home storage, effectiveness of fire protection measures

Defense

Safe use of lithium-ion batteries, military technical loads (e.g. shelling)

E-bike, e-scooter

Investigation of battery fires

Special applications

Transfer of existing know-how to any application and installation situation

Current research at EMI

Safe operation of home storage systems

Battery safety in electric vehicles

Safety of batteries under military loads

Safety of electronic devices in aircraft

Safe and sustainable polymer-based battery housings

Methods and models for fully digital sustainable product development

Focus topic “Battery safety”
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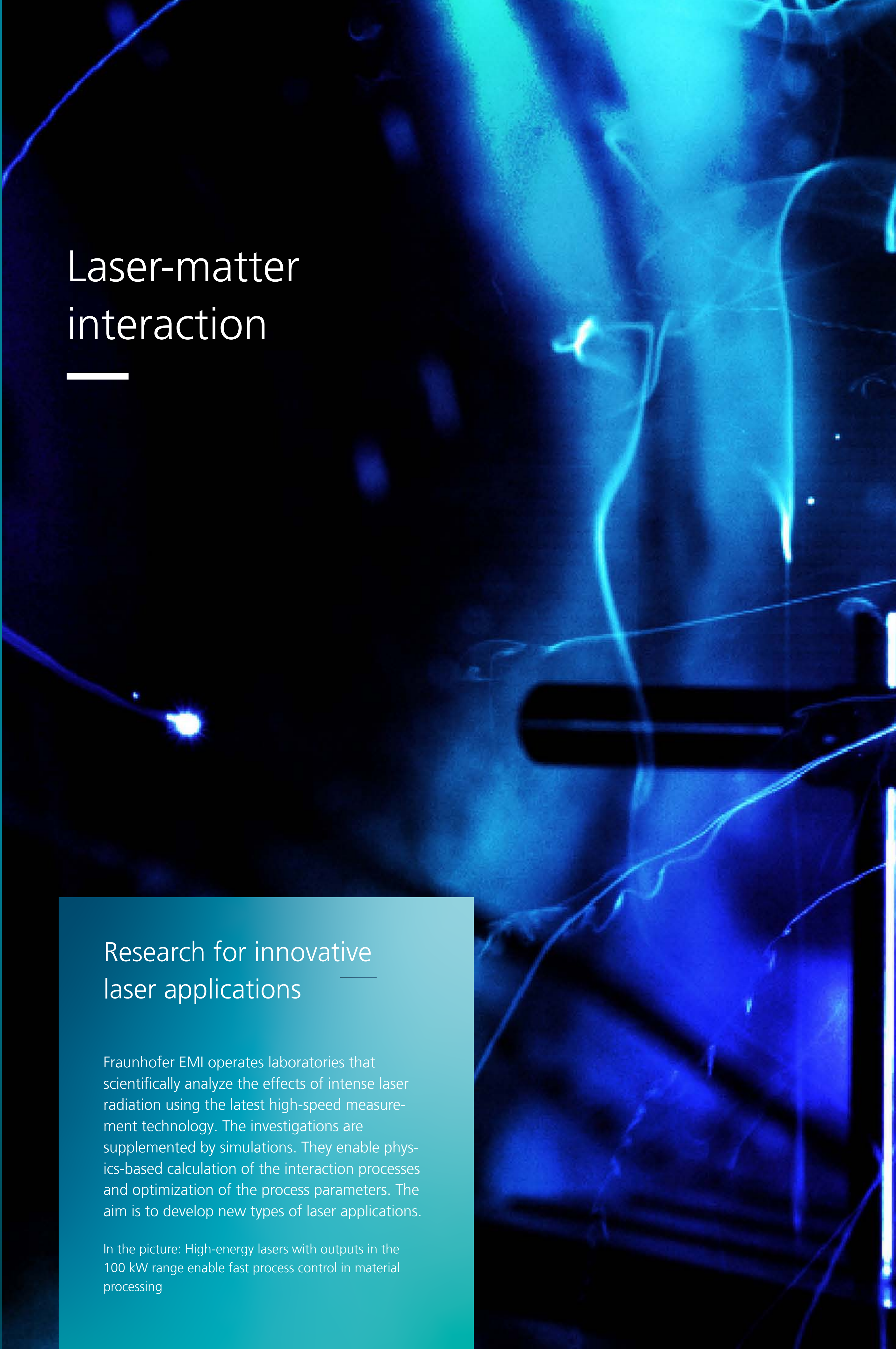
Photo: Fraunhofer EMI (2)



Laser-matter interaction

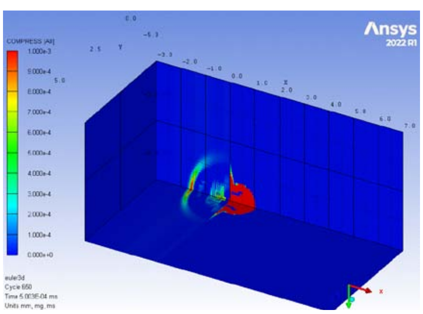
Research for innovative laser applications

Fraunhofer EMI operates laboratories that scientifically analyze the effects of intense laser radiation using the latest high-speed measurement technology. The investigations are supplemented by simulations. They enable physics-based calculation of the interaction processes and optimization of the process parameters. The aim is to develop new types of laser applications.

In the picture: High-energy lasers with outputs in the 100 kW range enable fast process control in material processing

In focus: developing laser applications of the future

From recycling to neutralizing explosive devices: Laser technology is a key element in the development of innovative processes. A detailed understanding of laser-matter interaction is a crucial basis for this.



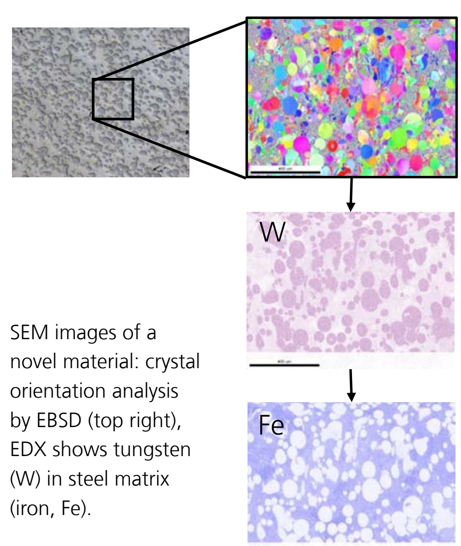
Simulation of laser ablation supports process control work.

Artificial intelligence monitors machining processes

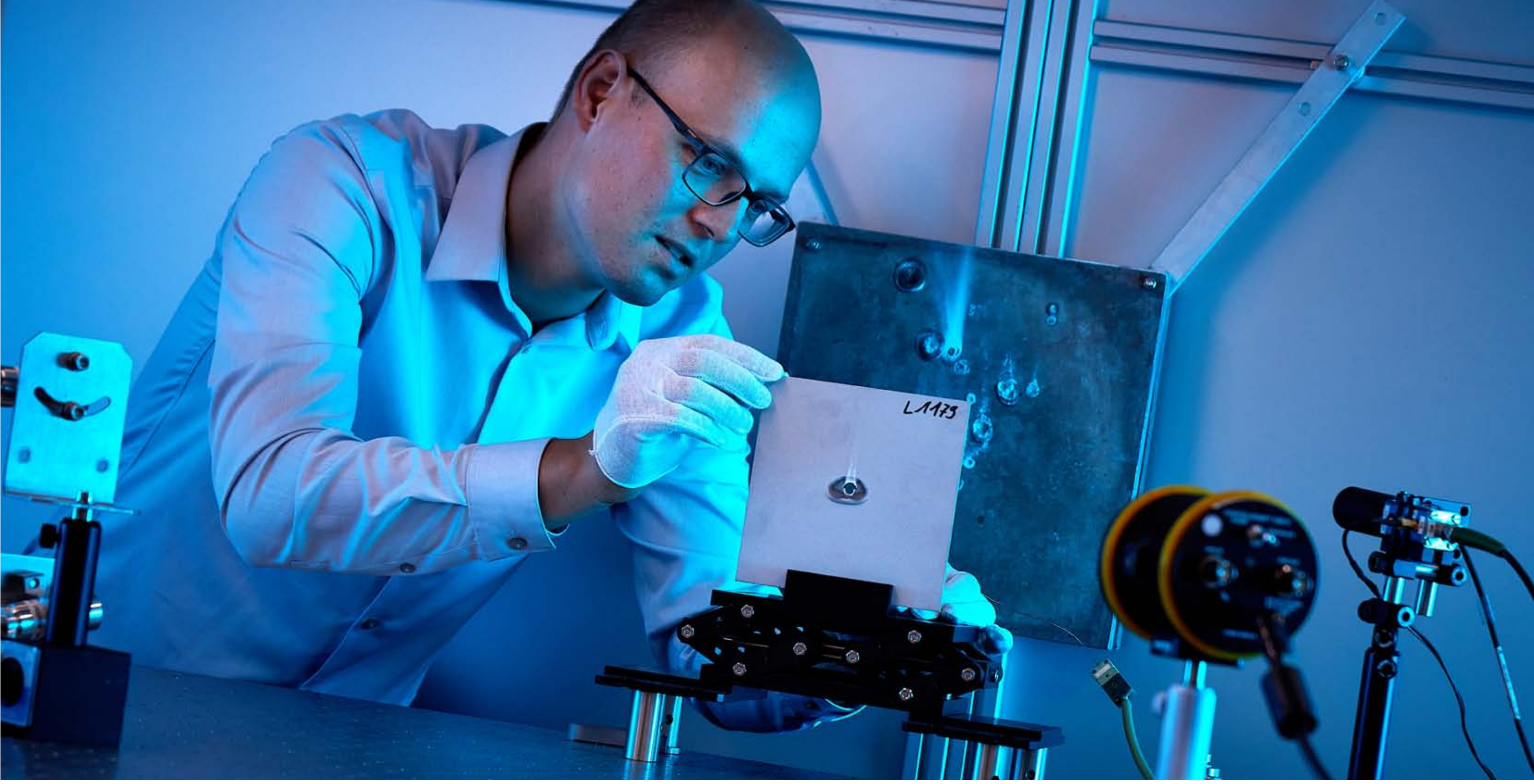
What potential does artificial intelligence have for laser material processing? In the RAPID-KI project, EMI is working with other Fraunhofer institutes to research the possibility of using data-based methods for process control during material removal with pulsed lasers. Possible applications include the recycling of electronic components and the paint stripping of large aircraft parts.

Novel materials using additive manufacturing

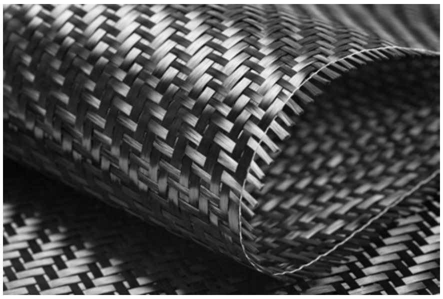
How can laser technology support the development of novel materials? Selective laser melting (SLM) is used in additive manufacturing, particularly for the production of geometrically complex metal components. By using special mixtures of metal powders as the starting material in conjunction with the appropriate process parameters, new types of materials with customized physical properties can be developed. In this context, Fraunhofer EMI is in particular conducting research on the production of metal-matrix composite materials that are characterized by high hardness combined with high plastic deformability.



SEM images of a novel material: crystal orientation analysis by EBSD (top right), EDX shows tungsten (W) in steel matrix (iron, Fe).



Innovations through high-performance laser technology: new opportunities for numerous fields of application.



Carbon fiber fabrics without matrix.

Recycling composite materials

How can composite materials be reused in a way that conserves resources? Composite materials such as carbon fiber reinforced plastics (CFRP) have great potential in lightweight construction due to their high stability combined with low weight and are used in the aviation and automotive industries in particular. The recycling of disused components is still an unsolved problem. Fraunhofer EMI is researching laser-based technologies that enable the reuse of carbon fibers.

Neutralizing explosive devices

How can laser technology increase security during defusing processes? The neutralizing of explosive devices always poses a risk for the emergency services involved – be it when old world war munitions are found or in connection with terrorist attacks. The use of laser technology for the controlled disposal of explosives and the delaboration of unexploded ordnance has been researched in special laboratories at Fraunhofer EMI in international projects. The security of the emergency services can be significantly improved by the possibility of using laser radiation over long distances.

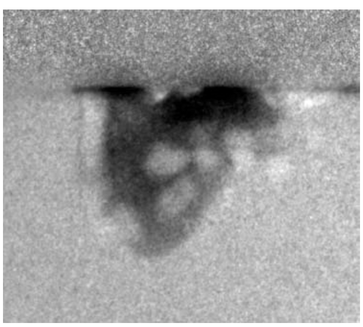
Pipe bomb model torn open by laser neutralization.

Photos: Fraunhofer EMI (4), vitals / stock.adobe.com

Application potential of high-power laser radiation up to 120 kW

What new possibilities do high-power laser sources offer in material processing? Typical laser sources used to date in industrial production for welding and cutting operate with beam powers in the order of 10 kilowatts. Thanks to recent advances in laser technology, lasers in the 100 kilowatt power class are already commercially available today. Fraunhofer EMI is investigating industrial applications for this new generation of laser sources, such as for rapid material removal or surface hardening. The development of new types of high-performance processing optics is also being addressed in this context.

Steel workpiece rapidly hardened locally with 120 kW laser power.



In the X-ray video of a laser welding process (laser from top, to the left), the melt pool dynamics are visualized with tracers (tungsten powder, black in the video) (with University of Stuttgart, IFSW).

New insights through expertise in high-speed metrology

How can new metrological methods be used to improve process control and gain new scientific insights? Fraunhofer EMI is a world leader in the field of high-speed metrology and uses this expertise particularly in laser technology. One current example is the establishment of a measuring station where laser-matter interaction is investigated using high-speed X-ray imaging. A linear accelerator makes it possible for the first time to visualize highly dynamic processes, particularly in thick metal samples.
This means that highly dynamic processes that take place inside samples during laser material processing can be visualized with a time resolution that has never been achieved before.

Developing new laser applications: Fraunhofer EMI uses a ytterbium high-energy laser.

High-energy laser with 100 kW

To date, lasers with an output of around 10 kW have been used in the industry for material processing. In the meantime, laser systems with outputs of over 100 kW have also become commercially available.

Fraunhofer EMI is investigating the interaction processes of such high-energy laser radiation with matter and developing new applications in the fields of materials processing, security and defense technology.

Current research at Fraunhofer EMI

Project: RAPID KI
Use of machine learning for process control in laser material processing.

Project: DigiTain
Application of laser technology for recycling hydrogen tanks made of carbon fiber reinforced plastics.

Project: Laser safety quantitative risk analysis
Software tool for assessing the security of free-field laser applications

Project: Topology optimization for multidisciplinary design problems
Software solutions and research service for industry.

Project: Expert tool laser effect
Investigation of fundamental interaction processes of high-energy laser radiation with matter and development of predictive computer models.

Photos: Fraunhofer EMI (6)

Focus topic "Laser-matter interaction"
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FOCUS TOPIC Highly-dynamic X-ray

Highly-dynamic X-ray

Really look inside

More high-quality data per experiment: The innovative research concept of X-ray simulation, X-ray experiment and analysis provides unique data and views.

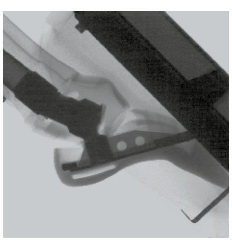
In the picture: X-ray simulation of a vehicle crash

Photo: Fraunhofer EMI

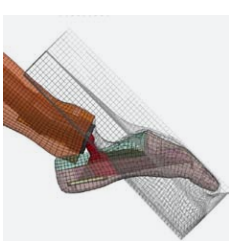
Opening up a new dimension with X-ray

Highly-dynamic X-ray with 1000 images per second

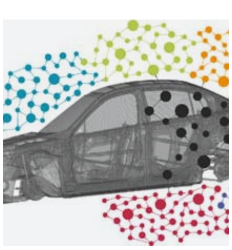
The technology makes it possible for the first time to experimentally validate the behavior of internal components and subsystems during the test.



Direct observation of critical processes
Until now, these processes could only be measured indirectly (e.g. using acceleration sensors) or reconstructed after the experiment. Highly-dynamic X-ray enables the direct observation of critical processes.



Millisecond-precise analysis and data feedback into the familiar working environment
The critical point in time at which a system tilts can be compared with the FE simulation with millisecond precision. If prominent areas in the X-ray image are tracked over time, it is possible to transfer the trajectories back to the evaluation software.



Linking design, process and material
The material is analyzed before, during and after the processes. By digitally linking design, process and material, solutions can be determined reliably and with maximum precision.

Photos: Fraunhofer EMI (3), Mercedes-Benz Group AG

Research crash-test facility at Fraunhofer EMI: Impact tests are carried out at component and complete vehicle level with impact masses of up to 3 tons and speeds of up to 80 km/h. The picture shows a complete vehicle test with the use of a linear accelerator.

Highly-dynamic X-ray crash: the technology in detail

Can you X-ray a car – just like a doctor? And all this in a high-speed collision?

At the Fraunhofer EMI research crash-test facility, a high-speed X-ray video is created during the vehicle crash.

Using a priori data and simulations, defined areas and specific components inside the vehicle are examined in advance.

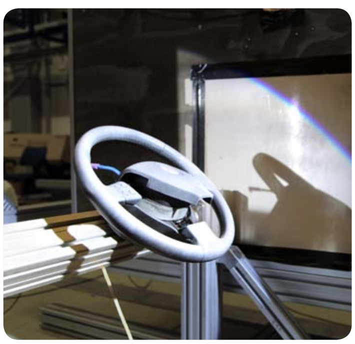
If FE simulation data is available, virtual preliminary tests can be carried out using the X-ray simulation developed in-house. This allows the experimental setup to be optimized. The observation window in space and time must be defined in such a way that important processes take place as transversely as possible to the direction of observation.

Markers are used for special questions – similar to those used in medicine. They are particularly easy to recognize in the X-ray image after imaging. Under these conditions, the results can be evaluated precisely.

An X-ray video is generated from the raw data using digital image processing algorithms. It is processed in such a way that internal processes can be easily understood. In addition, digital pattern recognition techniques can track features and record their trajectories quantitatively.

Application examples

The relevant processes in experiments often take place hidden inside. There are many reasons for this: complex component structures, overlapping multi-level protection concepts or cladding. With all these limitations, highly-dynamic X-rays provide a direct insight.



Dummy head impact on the steering wheel

Accurate detection of the head position – despite airbags
A large number of airbags are deployed during the crash test of modern vehicles. The curtain airbags in particular block the view of the dummies inside the vehicle. Acceleration sensors, interior cameras and color markings only provide an incomplete picture. Highly-dynamic X-rays can be used to film the exact position of dummies in the vehicle: How close has the head really come to the steering wheel? Are there elastic deformations that are no longer recognizable after the crash?

Recording the NCAP MPDB test more precisely

X-rays provide answers about the crash sequence
In the MPDB test, the front end of the car penetrates deep into the honeycomb barrier. During the evaluation, the plastic deformation is measured with millimeter precision after the crash. But how deep does the vehicle penetrate and when? When does deformation occur in the crash structure in the barrier? How large is the maximum elastic deformation? X-rays can provide answers to these questions.

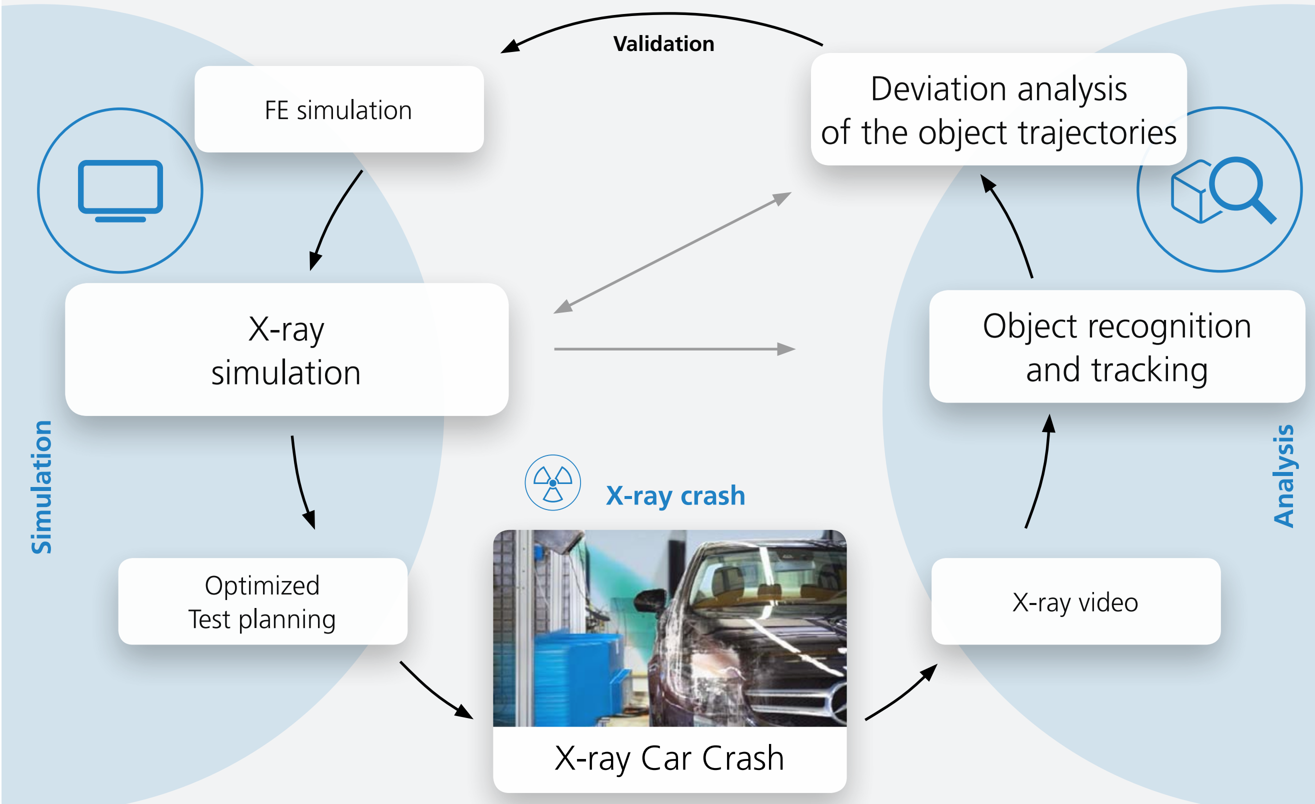
Complex, multi-layered crash structures

Investigate impact at the time of deepest intrusion
When protecting VRUs or occupants, dummies come into contact with multi-layered complex structures such as the A-pillar. Both outer layers and inner structures deform in the process. However, elastic deformation of the deeper structures or when failure occurs can no longer be detected after the test. Highly-dynamic X-rays can be used to examine the impact at the time of the deepest intrusion and to clarify the relevant issues.

Photos: Fraunhofer EMI (6)

Flowchart X-ray Car Crash

Fusion between simulation and experiment Simulated X-ray images are generated for test planning on the basis of FE simulations. This data is used to optimize the test setup for maximum information gain. The X-ray video obtained in the experiment is subsequently analyzed. The data obtained enables the validation of the simulation models of previously invisible components.



Current research at Fraunhofer EMI

DigiTain – Digitalization for Sustainability

Publicly funded project by BMWK and the European Union.

SiKuBa

Secure battery housings made of plastic; publicly funded project by BMWK.

Grey-Box-Processing

Generation and use of hybrid data sets from incomplete measurement data with heterogeneous uncertainties with predictive FE structural simulations.

Focus topic “Highly-dynamic X-ray”

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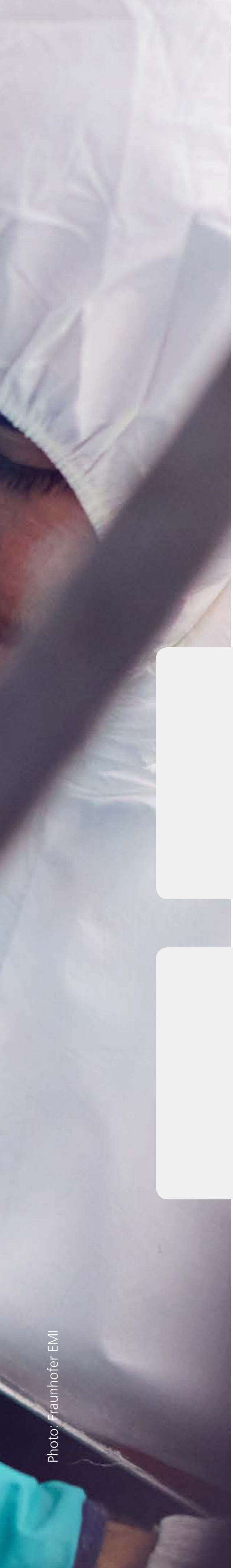


Business units at Fraunhofer EMI

Defense

Security & Resilience

Automotive

Space

Aviation

← **Increasing the security of battery systems**
Extensive battery testing can be carried out at the Efringen-Kirchen location. The testing is closely linked to accompanying simulations.

Photo: Bundeswehr / Marco Dorow

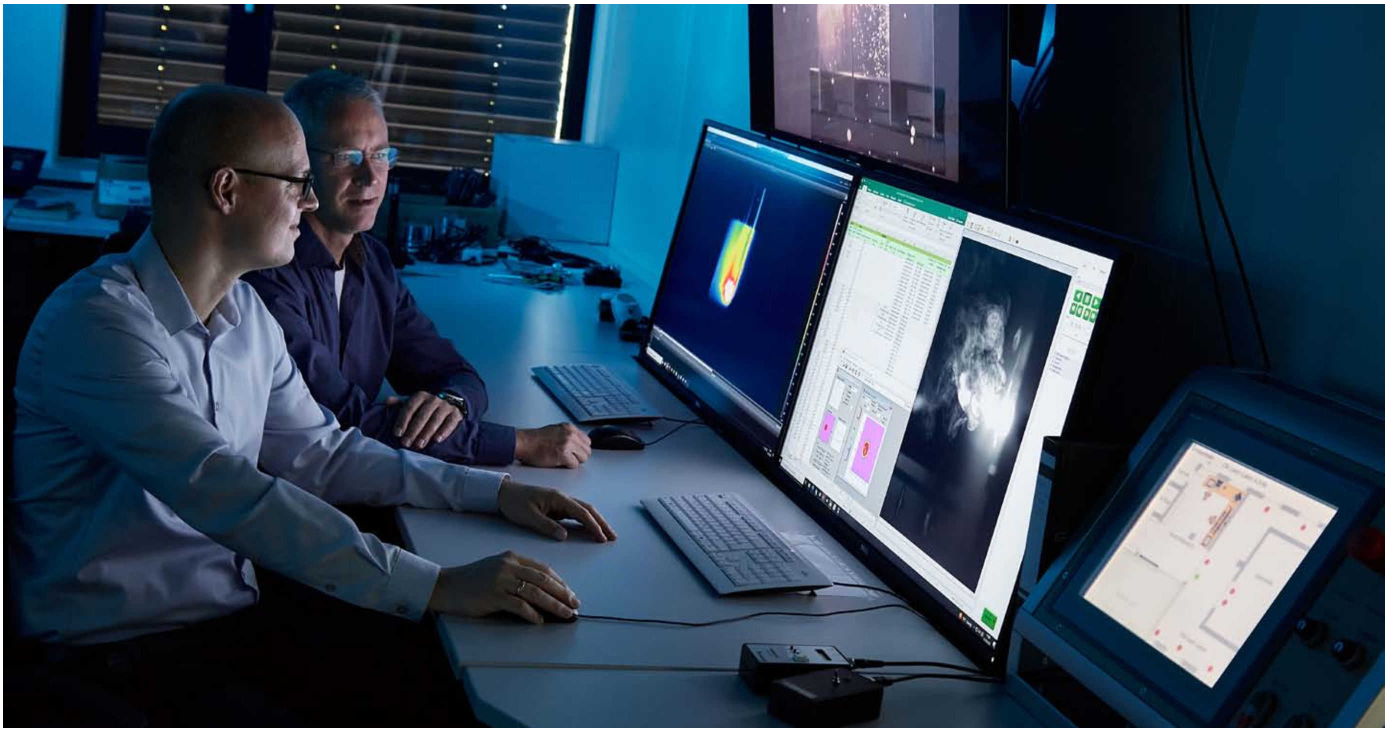
Armor and anti-armor for the German Federal Armed Forces

The Bundeswehr needs future-proof systems for land, air, sea and cyberspace. Fraunhofer EMI is therefore researching scientific and technological issues in the areas of armor and anti-armor as well as safety and security of military systems.

The institute is currently developing an electronic firing range limiter to enable the armored weapon to be tested not only in static but also dynamic test scenarios while maintaining firing safety.

Pictured: Exercise of the 393 Tank Battalion with Leopard 2A7V main battle tank.

Business unit Defense



Research for a Germany that can defend itself

After 30 years of cost-cutting and reductions in the German Federal Armed Forces, the Ukraine conflict has led to a turnaround. National and alliance defense have once again become the focus of attention. The expertise of Fraunhofer EMI is in great demand.

The institute is particularly grateful for the many years of extensive funding from the Federal Ministry of Defence.

By **Daniel Hiller**

Fraunhofer EMI has laboratories in which intense laser radiation is scientifically analyzed using the latest high-speed measurement technology. This allows laser applications of the future to be developed.

Turning point for the European security architecture

24 February 2022 marks a turning point that Europe has not experienced since 1945 in terms of security and defense requirements. The Russian war of aggression against Ukraine and the resulting breach of the internationally recognized rules of territorial integrity of sovereign states marks the end of one of the longest periods of peace in Europe's recent history.

The consequences of this war are having a massive impact on German security and defense policy – as well as on the German and European defense industry. As personnel and equipment have been reduced in all branches of the armed forces over the last 30 years, the Bundeswehr is now also facing major challenges.

While the political focus is once again clearly on national and alliance defense, the German defence industry and its capabilities are under massive production pressure for weapons and ammunition in the face of extensive demand at home and abroad.

Obsolete material and urgent need for new developments

Furthermore, the Bundeswehr operates technologies and systems in all branches of the armed forces whose life cycles have already been reached or even exceeded in many cases. In the spirit of strict budgetary discipline, existing material and equipment have merely been maintained and possibly upgraded in terms of their respective capabilities. Actual new developments of defense technology systems on a larger scale, linked to the accompanying research and development projects, have only rarely been initiated in the past two decades.

Here, too, the year 2022 has once again had a major influence on the actions of politics and industry in terms of new large-scale defense technology systems. With the two development projects Future Combat Air Systems (FCAS) and Main Ground Combat System (MGCS) initiated jointly with France before 2022, two projects are to be pursued in which German defense technology and research will make significant contributions.

Photos: Fraunhofer EMI (6)

Laboratory for 3D printing: The methods developed at Fraunhofer EMI for efficient process parameters shorten development times and enable extremely high material quality.

Research at Fraunhofer EMI

In light of these developments, the research work at Fraunhofer EMI in the area of force effectiveness and protection are of great interest to our public-sector clients in the German armed forces as well as the defense industry. Whether in the field of air defense, vehicle protection, 3D printing processes for defense-relevant parts and protective components, whether in the context of developing simulation tools for highly complex explosion events in a military context or in the course of personal equipment for soldiers in action: Fraunhofer EMI's expertise is in high demand.

On the following pages, researchers from various projects report on their research at Fraunhofer EMI: from the basics of technology research to the production of functional illustrations and software prototypes. They show how innovations are made possible that ultimately provide the Bundeswehr with new solutions in the field of force effectiveness and protection.

Services at EMI

Analysis of effect and protection mechanisms

Computer simulation of impact and shock wave events

Development of sensors and electronics for extreme conditions

Short-term measurement technology, e.g. X-ray diagnostics

Material characterization and failure analysis

Analysis of the technical safety and reliability of defence systems

Shooting safety for tanks in dynamic test scenarios

The capabilities of weapon systems designed for use in dynamic deployment scenarios cannot be fully investigated in purely static test scenarios.

This gives rise to the need for a way of investigating weapon systems in dynamic scenarios while maintaining firing safety. A firing range limitation system developed at Fraunhofer EMI monitors the position and orientation of the weapon system. This system can be used to automatically restrict the release for firing to permissible ranges.

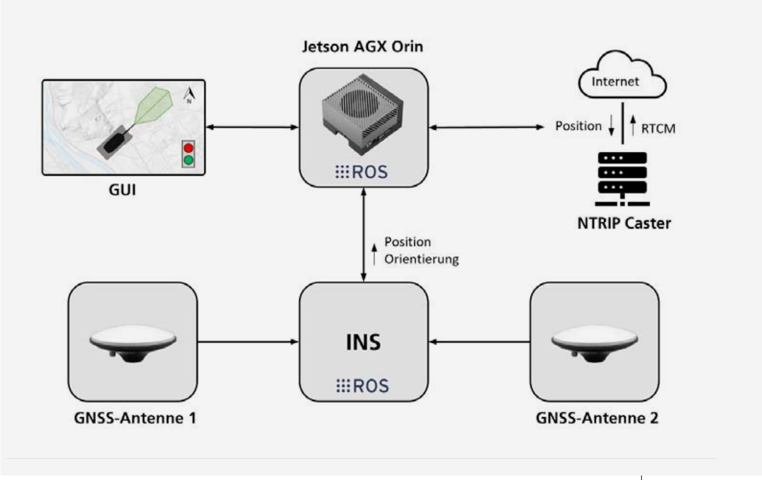
Development of an electronic firing range limiter
As part of a feasibility study with the Unterlüß Test Center (EZU) of Rheinmetall Waffe Munition GmbH, Fraunhofer EMI is developing an electronic dynamic firing range limiter that can be adapted as an external attachment to a Leopard 2 main battle tank (selected here as an example). A functional illustrator was developed that can be mounted on the vehicle via a standard interface for testing with only minimal system intervention and can be removed again afterwards.

In contrast to conventional mechanical range limiters, this is a multi-sensor platform that can also be used in driving mode. The system uses GNSS (Global Navigation Satellite System) to measure its current position and an inertial measurement system to measure its movement. Based on the local conditions of the test site, a GIS-supported analysis (Geographic Information System) incorporating the merged sensor data is used to determine in real time the permissible weapon orientation and weapon position in which a shot may be fired. Depending on the ammunition, vehicle speed and space conditions, the precision and speed requirements are technically challenging. Added to this is the load caused by the shot, against which the system must be hardened.

Real-time analysis for reliable weapon alignment
There are three main requirements: Measurement deviation of the azimuth, output data rate of position and orientation, and the shock resistance of the system.

A satellite-based inertial navigation system (INS) is used to determine the absolute orientation of the gun. The INS provides continuously updated information on the vehicle's orientation, while two GNSS multiband antennas are used to correct the azimuth. Using real-time kinematics (RTK), it is possible to specify the antenna positions in a range between 1 cm and 2 cm.

The Jetson AGX Orin developer kit from Nvidia is used for the real-time evaluation of the shot release and the processing of the fused sensor data from the INS.



Shooting safety for tanks
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Photos: Fraunhofer EMI (2)

Generative design for components of the ERNST nanosatellite: Multidisciplinary requirements are the rule for space hardware.

3D printing in military contexts: faster and more cost-effective

How Fraunhofer EMI uses generative algorithms to create efficient engineering designs and solve complex design problems.

Automated tools for design, simulation and optimization are indispensable in modern engineering today. One example of this are generative algorithms such as topology optimization, which can automatically create efficient construction designs. Fraunhofer EMI uses innovative software solutions and specialized research services to solve complex design problems.

Use of intelligent algorithms in component design

Intelligent algorithms can overcome the limitations of traditional design methods. Fraunhofer EMI uses these technologies to efficiently tackle multidisciplinary problems such as vibration behavior, energy absorption or thermal conductivity. The use of generative algorithms makes it possible to find the right balance between mass, performance and robustness.

AI-supported concept design

In the early phase of product development, AI-supported methods help to solve multi-objective problems. Fraunhofer EMI combines AI models, which show their strengths in variant generation, with numerical and analytical approaches to develop functional, sustainable and cost-optimized solutions. Although solving partial differential equations is challenging, AI-supported methods offer enormous potential.

Expert solutions as a service

Fraunhofer EMI offers comprehensive services ranging from consulting to implementation and training. These services support the use and automation of specialized workflows as well as specific use cases where standard tools are not sufficient.

Additive Manufacturing
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Better protection for soldiers

Biomechanical analyses for personal Protection technologies and body protection

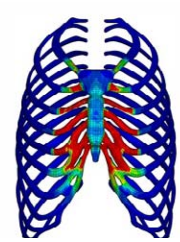
Human models GHBMC F05 and M50 from Elemance with soft ballistic vest and simulated impact in the center of the chest.

Injuries caused by deformation of protective equipment

Behind Armor Blunt Trauma (BABT) is caused by non-penetrating ballistic impacts caused by the rapid deformation of personal protective equipment (PPE). During the impact, the PPE and the underlying body tissue deform rapidly. This highly dynamic load can cause bruises, tears, fractures and injuries to organs. A measurement of the maximum deformation depth in ballistic sound ("back-face deformation", BFD – limit value of 44 mm first defined in 1979 by the US Department of Justice) is still used almost worldwide today for the certification of protective vests. However, there is no direct causal relationship between BFD and the severity of the resulting injuries in humans. Numerical human body models ("HBM") can now be used to question these ballistic limits and to investigate this special form of ballistic load depending on the body region. Fraunhofer EMI is pursuing the goal of developing virtual calculation methods with a high level of predictive capability in order to be able to analyze issues relating to impact-like load effects on the body when using personal protective technologies. This will expand the assessment capability for PPE and body protection.

Experimental analysis of load effects

A high level of predictive reliability of numerical calculations is supported by experimental validation. Suitable surrogate materials are required for this. The targeted development of surrogate bone materials for ballistic dummies is currently part of a dissertation at EMI entitled "Simulation methods for the predictive analysis of bone surrogates". Conventional crash test dummies from the automotive industry are to be further developed and used for military or police purposes. This means that the effectiveness of personal protective equipment can be investigated experimentally at Fraunhofer EMI when worn with the aid of dummies. The use of numerical human models also enables the quantitative assessment of injury risks and thus a better design of PPE products, which is associated with greater protection against injuries. An additional modeling method was developed for this purpose in order to convert simple textile elements from a 2D form into a 3D form that adapts to the virtual body surface. This technique is generally a simple means of draping flexible objects over three-dimensional contours.



Rib bone expansions and forces acting on the rib cage.

Protection technologies and body protection
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Photos: Fraunhofer EMI (4)

Defense

Military infrastructure requires special structural protection. A study by Fraunhofer EMI helps with the use of sustainable materials. Picture: Air base in Wunstorf

Structural protection for military infrastructures

Challenges posed by the switch to more sustainable materials for buildings with protection requirements

National and international agreements to reduce greenhouse gas emissions and the increasingly limited availability of traditional building materials are forcing the construction sector to turn to alternative, more sustainable building materials and construction methods.

This will also have an impact on buildings with protection requirements against physical threats. While the dynamic behavior and protection potential of conventional cement- and concrete-based solid building components are well researched, the behavior of components made of more sustainable building materials against these loads is largely unknown.

Catalog of materials: sustainable and protective at the same time

The study identifies suitable construction methods that meet the federal government's sustainability goals for federal buildings and at the same time meet the protection requirements of the defence sector. To this end, a catalog of materials was compiled and evaluated on the basis of sustainability aspects. In a second step, the materials and their use in components were evaluated on the basis of their mechanical properties and their ability to withstand dynamic loads based on projectile impact and air blast waves.

Planning aid for selecting suitable construction methods

This comparative analysis forms the basis for future experimental and simulation-based research work in order to quantitatively record the dynamic reaction of components made of sustainable materials. The research results are intended to support planners and client representatives in the selection of suitable construction methods that take into account both sustainability and protection aspects.

Structural protection of military infrastructures

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How vulnerable is infrastructure in foreign operations to explosions and shelling?

Fraunhofer EMI is developing a software-based analysis tool that can be used to quantify the protective effect of infrastructure in foreign operations against explosions and shelling. This makes it possible for operational planners to derive for which purposes existing buildings are suitable and which boundary conditions must be observed for new buildings in order to meet protection requirements during deployments.

New material models for precise simulations in terminal ballistics

For predictive simulations of terminal ballistics processes, it is essential to correctly describe the effects of dynamic loads in material models. These models are usually calibrated using special characterization tests, but these are not very representative of terminal ballistics.

At Fraunhofer EMI, data-based methods are used to simultaneously optimize model parameters for a wider variety of test types, including impact tests. The resulting material models describe the investigated materials significantly better than before and enable a significant increase in accuracy in the computer simulation of materials under highly dynamic loading.

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Photos: Bundeswehr / Rolf Klatt, Gorodenkoff / iStock, Fraunhofer EMI (2)

Business unit Security & Resilience

Technical resilience for disaster prevention

In 2023, southern Europe was hit hard by forest fires. Around 5,000 km² fell victim to the flames, which is twice the area of Luxembourg. More severe forest fires are expected in the coming years due to global warming. On the following pages, you can read how technical resilience helps to better manage disasters and how Fraunhofer EMI is specifically researching solutions for better firefighting.

Image: NASA satellite image of the forest fires near Alexandroupolis on 22 August 2023 with a plume of smoke hundreds of kilometers long drifting across the Mediterranean.

Photo: NASA

How technical resilience strengthens our security

Natural disasters, crime, terrorist attacks – these phenomena have one thing in common: their occurrence can neither be completely prevented nor, in many cases, precisely predicted.

The need for the principle of resilience becomes apparent where traditional hazard prevention and mitigation reach their limits.

By **Daniel Hiller**

To bend, but not to break
Technical resilience is the ability of technical systems to remain functional or to recover quickly in the event of disruptions or unexpected events. This includes robustness, fault tolerance and flexible adaptation strategies to minimize failures and ensure operations.

Photo: Eduardo / stock.adobe.com

Engineering resilience for practical applications

Forest fires, hurricanes, extreme heatwaves and floods caused over 200 billion euros worth of damage last year. Cybercrime attacks are on the rise: on large and small companies, on public institutions such as municipalities, but also on critical infrastructures such as hospitals. Regarding terrorist threats, a whole series of attacks has illustrated how relevant this phenomenon remains for our open society.

Technical resilience strengthens our security by making systems and infrastructures more resistant to disruptions. This means that buildings, networks and other critical facilities are designed to withstand or quickly recover from shocks, natural disasters, cyberattacks and other threats. Redundancies, emergency systems and resilient materials can minimize the likelihood of failure and ensure continuity. Such measures are crucial to ensure the safety of people and important facilities.

Fraunhofer EMI conducts research in this field. It continuously strives to develop practical tools based on research.

Currently developed engineering solutions

– Together with an industrial partner, Fraunhofer EMI has developed software for extreme weather events. Among other things, it describes the resilience of the building structure in the event of flooding.

– In the event of major damage, entire infrastructure areas are affected in addition to individual buildings. Emergency services must quickly have a comprehensive picture of the situation and make many decisions about operations in a short time, which can mean the difference between life and death. In the EU project TeamAware, EMI experts are researching how the resilience of emergency services can be technically supported.

– In addition, Fraunhofer EMI has developed new simulation solutions at its Berlin location to simulate the behavior of large crowds in crisis situations. Such tools are enormously helpful for security authorities when considering security scenarios in the context of major events.

– On a large scale, an EMI solution in the field of power supply helps to quickly compensate for disruptions and failures in individual network areas and reduce cascading effects.

New guidelines to increase resilience

At the beginning of 2024, the BMBF published the 4th edition of the national civil security research program. With its range of services, Fraunhofer EMI ties in with all of the six pillars of the program. The new federal law to strengthen the physical resilience of operators of critical facilities, or KRITIS umbrella law for short, is also expected in 2024. As part of the implementation of a European directive to increase the resilience of critical entities, this new law is expected to give a strong boost to the topic of resilience in companies. Fraunhofer EMI can use its expertise to implement innovations together with industry. At the same time, the national strategy for increasing resilience published last year by the Federal Ministry of the Interior is being supported in a national platform for implementation. Fraunhofer EMI will participate in this platform and thus actively shape the strategic topics.

Learning resilience from nature
One example of resilience in nature is trees, which adapt to environmental influences through flexibility and strength and can withstand storms.
Pictured: a beech tree on the Schauinsland near Freiburg, Germany.

Services at Fraunhofer EMI

Risk analysis and physical security

Protection of buildings and infrastructures against extreme loads.
Components, buildings, districts

Resilience management and business continuity for companies

All risks, such as terror, hail, storms, landslides, floods, earthquakes

Resilience assessments and -design

Production systems, supply networks and supply chains

Vulnerable infrastructures: The disaster in the Ahr valley has shown how vulnerable our infrastructures are.

On the way to a resilient city

The resilience of built structures to flood events

In several projects, Fraunhofer EMI is researching the vulnerability of buildings and structural infrastructures to flood events in order to identify causes of failure, quantify possible damage probabilities and qualify improvement measures. The overarching goal is to strengthen the resilience of urban structures.

The central element is the development of generic building models. These are simplified mathematical models that take into account the typical characteristics of buildings in terms of their structure, materials and construction. These models represent a wide range of building types and can be used to assess the vulnerability of a large number of buildings to flooding without the need for specific data for each individual building. Probabilistic analyses of generic building models are based on the use of probability distributions for different parameters, such as the height of the flood or strength values of the construction materials. By combining these probability distributions, statistical statements about the probability of damage and risks can be derived.

Project "ResCentric"
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Photos: sophie1404 / stock.adobe.com, Christian / stock.adobe.com

New platform improves coordination of emergency services during large-scale operations

TeamAware project: Team Awareness Enhanced with Artificial Intelligence and Augmented Reality

In recent years, there has been a significant increase in large-scale civil protection operations. This poses a considerable challenge for emergency services, particularly in terms of coordination, response and communication. In the course of international disaster relief, the "TeamAware" project aims to help solve new and known problems in civil protection. It was developed as part of the European research initiative "Horizon2020". The project involves 22 international partners working together.

"TeamAware" pursues three approaches: firstly, the reduction of manual reporting. New sensor systems are used for this. Secondly, the use of decentralized data transmission and processing. Thirdly, user-friendly displays for emergency services at all levels.

Drones, smart clothing and various sensors are used in "TeamAware". For example, they measure the locations, body positions and heart rates of first responders. Chemical gases or audio and video recordings are also recorded. The collected data is collated and used individually. This also makes it possible to identify the stress and fatigue levels of the emergency services.

Fraunhofer EMI has developed a software platform in "TeamAware". This can analyze, process and evaluate data streams. The data is bundled using new algorithms. This increases its informative value. With the help of an AI-based decision support system, the current and past situation is analyzed and recommendations for action and indications of critical situations are given in real time. All data is then displayed in a clear overall situation picture, which has been developed according to modern and proven HMI aspects. With the help of this system, emergency services at tactical and strategic level are able to follow events live, assess them on the basis of the individual and combined data situations and react directly and immediately to changing factors.

In the context of safety research, Fraunhofer EMI has been able to make a decisive contribution with TeamAware to making first responders and emergency services fit for complex and challenging operational situations using new ideas and technologies and making their work safer and more effective.

Project "TeamAware"
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Photo: Andrii Chagovets / stock.adobe.com

Fighting wildfires more efficiently

New process improves aerial wildfire fighting

Fraunhofer EMI and the start-up company CAURUS Technologies GmbH are working together to develop a new type of extinguishing method. It is intended to improve the efficiency of fighting wildfires from the air.

Studies have shown that optimizing the size of the water droplets and the position of the cloud have a strong influence on extinguishing success. These are critical elements in bringing the temperature of a fire below the ignition point and depriving the fire of the oxygen required for the combustion process.

The process allows vegetation fires to be fought considerably faster and the efficiency of water use is multiplied. The future mechanism for the targeted generation of a water-aerosol cloud is already being promoted in phase 2 of the Fraunhofer DeepTech Accelerator AHEAD.

Effective extinguishing of wildfires
In recent years, around 5000 to 10 000 km² of forest have fallen victim to the flames every year. CAURUS Technologies and Fraunhofer EMI are working on a new mechanism that creates a more efficient extinguishing cloud.

Efficient extinguishing process
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Resilient electricity grids for the energy transition

The elimination of base load-capable power plants and the increasing electricity demand for heat pumps and e-mobility require a new architecture for the electricity grid

The traditionally strongly hierarchically structured electricity supply in Germany is facing serious upheavals. The energy transition requires a transition to a new architecture characterized by decentralized energy generation at lower grid levels and the elimination of traditional guarantors of stability in the form of large power plants. On the consumer side, the increasing spread of heat pumps and e-mobility is increasing the demands on the electricity grid. At the same time, climate change is leading to more frequent and more severe extreme weather events.

Development of a resilience monitor

In the RESIST project, five Fraunhofer Institutes – EMI, IEE, ISE, ISOB-AST and IEG – are pooling their expertise with the aim of increasing the resilience of the power supply under these conditions.To this end, current technologies in the field of power supply are being further developed through simulations and tests of new hardware. Based on the resulting findings, Fraunhofer EMI is applying resilience management strategies to map resilience in the power supply in a structured and comprehensive manner. A catalog of key resilience indicators is now available for this purpose, which is used in the specially developed Resilience Monitor (R-Monitor). The R-Monitor maps the resilience of the electricity supply over time based on the consolidation of a wide variety of data sources, taking into account the risks and opportunities of newly introduced technologies and methods. This is achieved, among other things, by implementing a tool developed at Fraunhofer EMI as part of the project. This tool describes the dynamic behavior of a transmission grid after hypothetical outages and thus enables a stability assessment of the current grid status.

Fraunhofer EMI is also developing a network model that uses the in-house software tool CaESAR to map the consequences of a power outage for critical, interdependent infrastructures.

New impetus for 2024

In November 2023, based on the results of RESIST to date, a workshop was held at EMI focusing on the topics of "Resilience in grid planning" and "Prospects for distribution grid islands". The solutions developed so far were met with great interest by the invited stakeholders, from grid operators to civil protection. The exchange also provided new impetus for the year 2024. Many challenges still await innovative solutions for the resilient conversion of the electricity grid.

"RESIST" project
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Sustainable and resilient Logistics: SARIL Kick-Off

The EU-funded project SARIL (Sustainability And Resilience for Infrastructure and Logistics networks) aims to provide decision support for resilient and sustainable logistics. SARIL is also developing recommendations for dealing with disruptions and for green business models for logistics companies and authorities.

The project is being led by EMI and will be carried out by an international team of scientists and industry partners over a three-year period starting in June 2023.

Resilient logistics ensures that goods and raw materials are transported and distributed reliably even in the event of disruptive events such as natural disasters, supply bottlenecks or political crises.

Fraunhofer EMi is proud to contribute its expertise in the field of resilience directly on site in Freiburg.

Freiburg RESIST

The FreiburgRESIST project is one of the five winning projects in the BMBF's "SifoLIFE – Demonstration of innovative, networked security solutions" competition. The aim of the joint project is a dynamic, networked resilience management system. The aim is to improve the planning of major events, evacuation in crisis situations and communication between emergency services.

Fraunhofer EMI is involved as a development partner with the topics of crowd monitoring and forecasting as well as hearing and visibility analyses.

Business unit Security & Resilience
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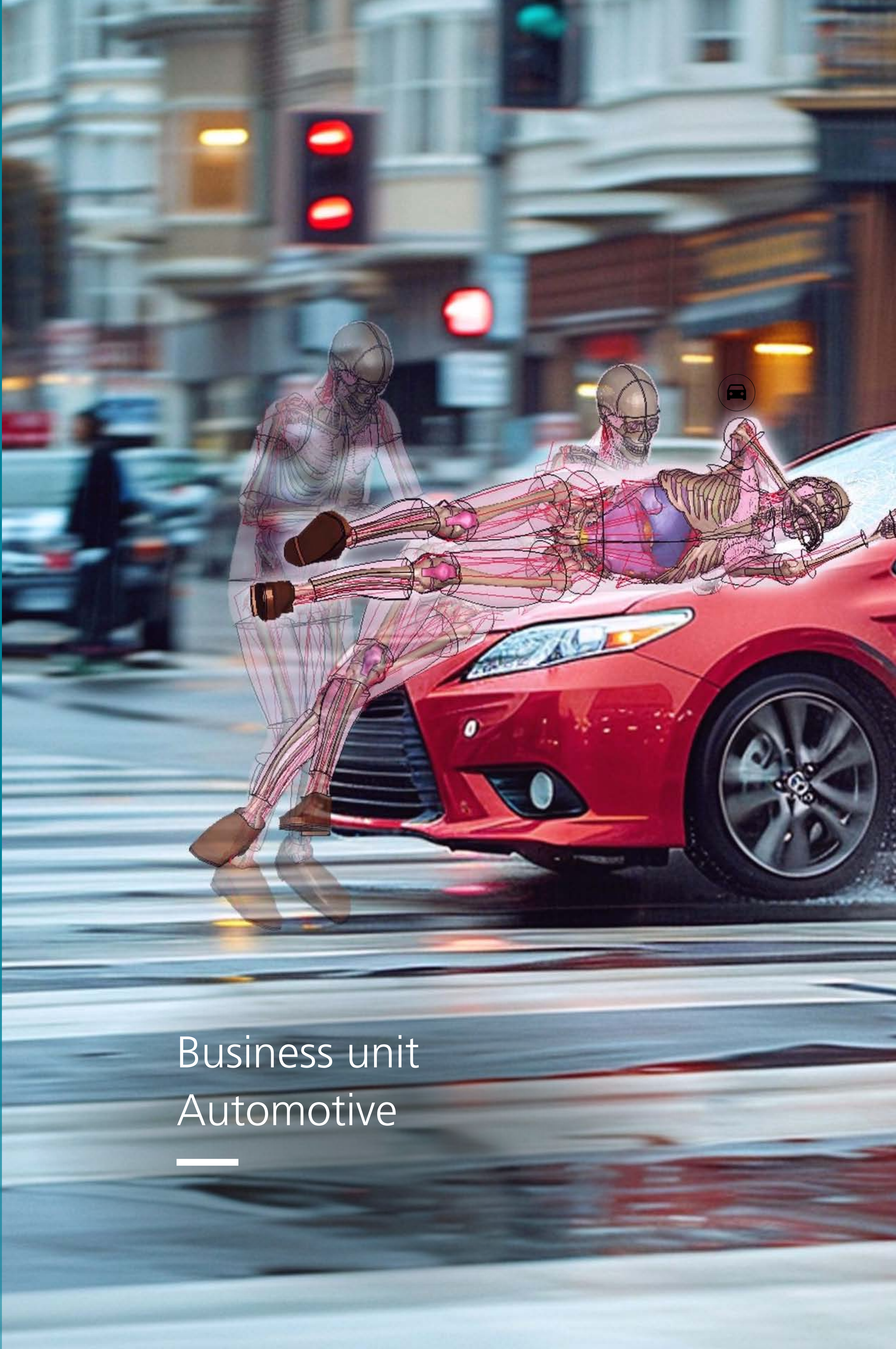
Photos: Fraunhofer EMI (using Midjourney) (2), Patrick Seeger / City of Freiburg, Fraunhofer EMI



Business unit Automotive

Getting tomorrow’s road safety on track today

Innovative technologies are key to making the traffic of the future safe: intelligent infrastructures, cars that communicate with each other and assistance systems that correct driving errors, protection of vulnerable road users and the safety of battery-electric vehicles.

Pictured: Attention project. AI-optimized vehicle behaviour in the event of a collision

Photo: Fraunhofer EMI

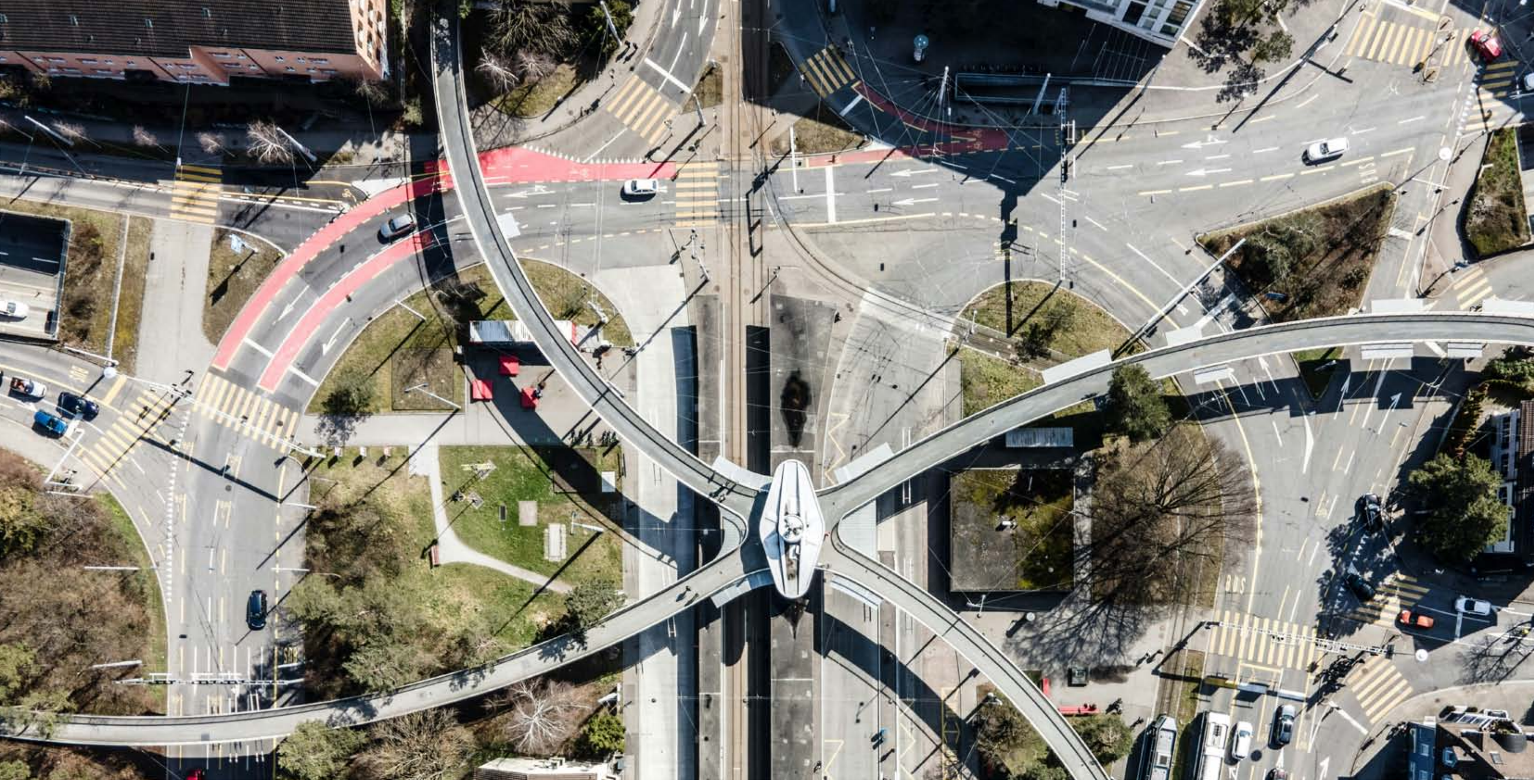
Automotive

Safety for all road users

The mobility system faces complex challenges: In the future, it should not only be CO_2-neutral and demand-oriented. People from all population groups should be able to get around safely and carefree, whether by bike, car or on foot. Unfortunately, we are still a long way from the so-called “Vision Zero” – no traffic fatalities – at the moment.

The concepts developed at Fraunhofer EMI are intended to help increase the safety of all road users.

By **Dr. Jens Fritsch**



Increasing complexity: Fraunhofer EMI is developing concepts to make the transportation of the future safe and resource-efficient. Aerial view of Bucheggplatz in Zurich, Switzerland.

Road traffic will change significantly in the coming years. Increasing automation, the introduction of battery-powered electric vehicles and the diversification and multimodal orientation of transport pose new challenges for vehicle and road safety.

Vision Zero

Mobility is the foundation of our economy and society. It is a prerequisite for functioning markets and has a decisive influence on the prosperity and quality of life of our citizens. Mobility must be sustainable, i.e. environmentally, economically and socially compatible. Above all, however, it must be safe. After all, traffic accidents cause great suffering for the people involved, but also for their families, relatives and friends.

The ambitious goal of "Vision Zero" is to ensure that no one in Europe will die in a traffic accident by 2050. Not least thanks to the successive road safety programs of the German government, road safety in Germany has improved continuously over the last few decades. The number of road deaths has fallen by more than 75 percent since 1970. This success can be attributed to a variety of factors, including the introduction of new safety technologies in vehicles, improvements to road infrastructure and raising road users' awareness of the dangers of road traffic. However, not all road users are participating equally in this positive accident trend: for example, the number of serious injuries is stagnating. In addition, the number of unprotected road users such as pedestrians and cyclists killed in road traffic is currently rising.

Furthermore, road traffic will continue to change in the coming years. Increasing automation, the introduction of battery-powered electric vehicles and the diversification and multimodality of traffic pose new challenges for vehicle and road safety.

Vulnerable road users

One important area of research is the safety of vulnerable road users such as pedestrians, scooter riders and cyclists. The aim here is to find solutions to prevent accidents and minimize the risk of injury. Research is being carried out into the development of advanced assistance systems that draw the driver's attention to vulnerable road users and provide early warning of potentially dangerous situations. This can be done, for example, by using cameras, radar sensors and artificial intelligence.

Photos: Fraunhofer EMI (using Midjourney), Patrick Federi / unsplash.com

In the ATTENTION project, EMI and its consortium partners are researching a method for real-time injury prediction of vulnerable road users. Data-driven methods are used to determine a situation-specific risk of injury from vehicle-based video data and virtual tests with digital human models. In the future, injury prediction will enable both safe and efficient traffic through risk-minimizing strategies of the automated vehicle.

Key results of the project include the development of a position and movement database for pedestrians and cyclists. Data from Bosch accident research will be analyzed and used as the basis for biomechanical and AI-based motion prediction. Finite element crash simulations then provide potential injury patterns, which are compared with real accident data and stored in another collision and injury database. The results of the crash simulations serve as training data and form the basis for the AI-based prediction of situation-specific injury values, from which an injury risk index is derived. Further measures, such as a change in driving behavior, are derived on the basis of the injury risk index. This is implemented in a virtual demonstrator.

Autonomous driving functions

Autonomous vehicles have the potential to make road traffic safer by reducing human error. However, numerous technical and legal challenges still need to be overcome to ensure the safe integration of autonomous vehicles into road traffic. One of the aims of research here is to improve the reliability and safety of autonomous driving functions.

Together with its consortium partners in the KIsSME research project, EMI is addressing the question of which traffic situations are relevant for safeguarding autonomous driving functions. Testing and validating highly automated vehicles requires large volumes of data, which must cover accidents and critical situations in particular.

Recording traffic situations with test vehicles makes an important contribution. However, the volumes of data generated are so large that capacity limits are quickly reached. The development of selection algorithms that enable the targeted recording of relevant driving situations directly in the recording vehicle is the main objective of the KIsSME project funded by the Federal Ministry of Economics and Climate Protection (BMWK). In close cooperation with the project partners, EMI has developed an evaluation system that estimates criticality from the vehicle movement data. A predefined selection of metrics, which are first transformed into individual criticalities using scaling methods, is the most important starting point for the system. These can then be combined into an overall criticality. The evaluation system can be used both to identify critical situations in existing data sets and to trigger a data storage required in the project.

Electromobility

Electromobility is a crucial key component for sustainable individual mobility in the future. An essential core element of all electric and hybrid vehicles is the storage of electrical energy in high-voltage batteries. Their integrity determines whether an accident results in damage comparable to conventional vehicles, a vehicle fire or even an explosion. The latter is the result of overheating (thermal runaway) of the battery, which can be caused by a short circuit or the destruction of the internal cell structure, for example. To assess crash safety, it is therefore necessary to better understand possible cell deformations and evaluate them in relation to the occurrence of a short circuit.

To this end, EMI has established a new method for the X-ray diagnostic investigation of the failure of lithium-ion cells under extreme conditions. This technology represents an important milestone in the analysis of battery failures, as it makes optically inaccessible processes inside the cell visible. An X-ray diagnostic tube is used for this purpose, which enables video recordings of up to five seconds in duration

Photo: Fraunhofer EMI (using Midjourney)

Which traffic situations are relevant for safeguarding autonomous driving functions? Large amounts of data are required, which must cover accidents and critical situations in particular.

and frame rates of up to 2000 images per second. To investigate penetration processes, such as those that can occur in a vehicle crash, a device was set up with which cells of different formats can be damaged by puncturing and thus caused to fail. Video recordings of such an experiment allow observations to be made at different points in time after the penetration and thus enable a deeper understanding of the internal cell processes.

Overall, there are a large number of research activities aimed at making road traffic safer for everyone involved. The safety of unprotected road users, the safeguarding of autonomous driving functions and the safety of vehicle batteries play an important role in this. We can only create a safe traffic environment for everyone through continuous research and development.

Current research at Fraunhofer EMI

ATTENTION
Artificial intelligence for real-time injury prediction; publicly funded project by the Federal Ministry of Economic Affairs and Climate Action (BMWK).

KIsSME
Targeted recording of relevant data for the further development and validation of automated driving functions; Publicly funded project by BMWK.

X-Ray Car Crash
Internal research project to develop a new type of measurement and evaluation method that uses X-ray diagnostics to observe the dynamic behavior of hidden vehicle structures under crash load.

AVEAS
Collecting, analyzing and simulating safety-relevant traffic situations; publicly funded project by BMWK.

The transparent crash

Together with Mercedes-Benz, Fraunhofer EMI has carried out the world's first X-ray crash – with 1000 X-ray images per second.

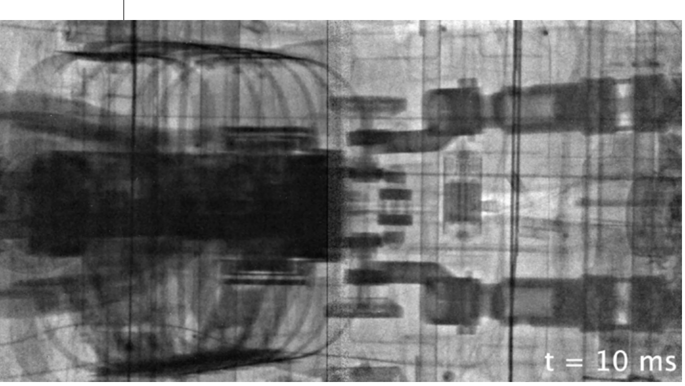
What exactly happens during a crash? When does the crash-absorbing structure fold? Does the A-pillar and occupant dummy interact? How deep does the dummy head penetrate into the airbag and how close does it come to the hard structures?

These important questions are to be answered in a crash test using a large number of sensors and high-speed cameras. A completely new type of technology has now been added that can visualize previously invisible deformations and their exact sequences in high resolution: Together with Mercedes-Benz, Fraunhofer EMI has carried out the world's first X-ray crash with a passenger car. Fraunhofer EMI uses a linear accelerator as an X-ray source and combines it with a high-speed detector. This makes the relevant areas inside a vehicle visible with a high temporal resolution of 1000 images per second and high X-ray energies of up to 7.9 million electron volts.

In order to protect the researchers and the environment from this radiation, extensive radiation protection construction measures had to be carried out at Fraunhofer EMI crash hall. In addition to the physical shielding, a complex technical safety concept was developed and implemented that combines radiation protection on the one hand and the necessary flexibility for research operations on the other in the best possible way.

The test in detail

The first X-ray crash was a side impact with an MPD barrier. The barrier hit a C-Class sedan at 60 km/h vertically from the side. A female dummy optimized for the side impact was sitting in the driver's seat inside the vehicle. In the dummy, in the vehicle and in the crash hall, dozens of measurement channels recorded accelerations, speeds and high-speed videos. The X-ray crash technology monitored the area of the dummy in the driver's seat. Underneath the vehicle was a 40 cm x 80 cm X-ray detector, which was developed together with the Fraunhofer EZRT. The linear accelerator, weighing more than 2 tons, was positioned under the hall ceiling. Held by counterweights, the linear accelerator floated on a linear-guided XY table. This ensures maximum clearance for the crash below the X-ray source and at the same time highly accurate positioning of the focal spot.



The impact of a crash lasts 0.1 seconds.
During this time, the technology developed at Fraunhofer EMI generates a video with 100 X-ray images. The images provide information about hidden processes during the crash.

Synchronous to conventional measurement technology, 1000 X-ray images per second were taken during the crash test. The design of the X-ray experiment, based on many years of research, enabled a precisely planned view of the internal dynamics of the crash test that had never been visualized before. Shortly after the impact, the incipient deformation of the side of the vehicle can be seen. The deploying airbags prevent conventional cameras from obtaining a detailed view of what is happening inside the vehicle.

In-depth insights through X-rays

However, the movement of the dummy's left arm caused by the protective airbag can be seen in the X-ray image. As the experiment progresses, the increasing load on the dummy's torso becomes visible before the vehicle's protective structures finally absorb the impact and secure the vital protective space.
This now accessible information enables a deeper understanding of the complex interaction of the dummy with the restraint systems and allows targeted further development of the safety technologies in the vehicle.

World's first screening of a full-vehicle crash test at 1000 frames per second.

Photos: Mercedes-Benz Group AG (2)

Optimizing the safety of autonomous vehicles through data

The KIsSME project shows how innovative algorithms can filter out the critical moments in traffic from huge mountains of data, advancing research and technology while conserving resources.

The aim of the KIsSME project was to develop algorithms for efficient data acquisition in test vehicles. To this end, Fraunhofer EMI addressed the question of how safety-relevant situations can be identified from a vehicle's sensor data. A modular evaluation framework was developed as a core component, which enables the calculation of an overall criticality for the respective driving situation. Input variables are evaluation measures (metrics) that can be derived from the driving dynamics of individual road users and the relative movement of several road users to each other.

Safety-critical value ranges are identified for all metrics and scaled on this basis in order to obtain dimensionless and therefore comparable variables. The combination of the scaled metrics ultimately leads to the desired overall criticality. The main advantages of the system over previous approaches to criticality assessment are the modularity of the system when selecting the metrics and the ability to evaluate very complex driving scenarios by calculating an accumulated criticality value.

EMI has also implemented an AI method for generating new scenarios and predicting vehicle trajectories. These predictions can in turn be used to calculate more detailed metrics for criticality assessment.
The KIsSME project was completed in 2023. EMI employees are now concentrating on applying the knowledge gained in follow-up projects. In the AVEAS project, for example, methods for the data-based optimization of traffic simulations are being investigated, with the identification and simulation of safety-critical situations playing a key role.

Project "KIsSME"
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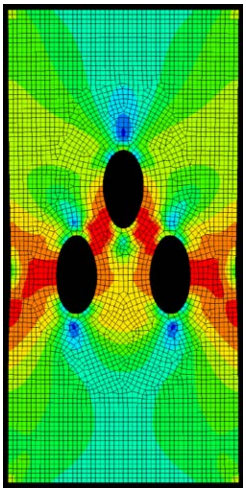
Novel material models with artificial intelligence

The application of machine learning creates new material models that can be used to design structures more safely and sustainably.



Over the past three years, EMI has been involved in the "AIMM" (Artificial Intelligence for Material Models) research project. Together with partners from industry and research, we have been working on the development of new types of material models.

Novel material models trained with test data

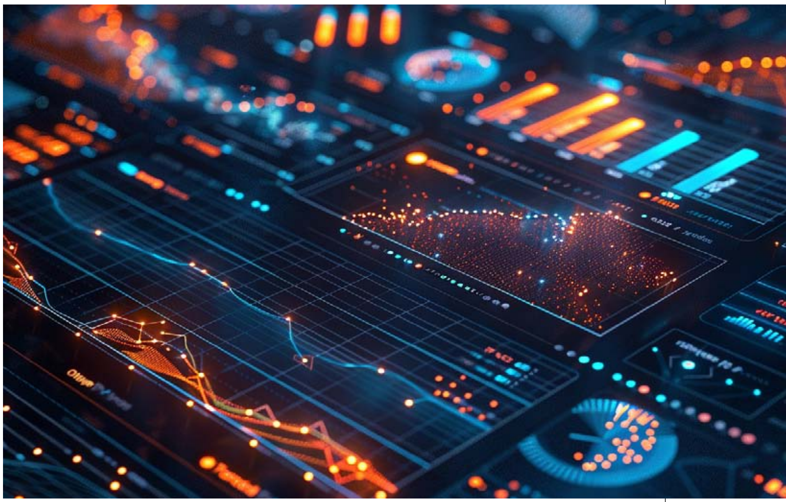
Put simply, a material model describes the behavior of a material under mechanical loading by providing the stress in the material for a given strain. Classical models are based on an analytical description and are calibrated using parameters derived from tests. In contrast, the new models learn the material behavior directly from test data using machine learning (ML) methods. This is intended to simplify the modeling of material behavior, which contributes to shorter development times and lower costs in vehicle development.

Optimized test specimens

This new approach to modelling also requires new concepts for material characterization. Conventional tests aim to generate precisely defined loading conditions in test specimens, from which the parameters for the models can be determined. In contrast, the new ML models require a large number of different states in a test specimen in order to provide a sufficient database for training. EMI has therefore developed optimized test specimens that can be used for the experimental determination of training data.

Missing stresses

One problem that arises when training with test data is the fact that mechanical stresses cannot be measured directly in tests. However, in order to be able to train the ML models, they must be told whether their predicted stress is correct or not. Together with the project partners, EMI has developed a method that can be used to train the models without having to know the stresses that occur in the physical tests. This is based on the fact that there is a force equilibrium at every point of a specimen at all times, which would be violated if the prediction of the material model were incorrect.
The AIMM project has made important progress in the field of ML material models, which will advance their future use.



Project "AIMM"

Thomas Haase, thomas.haase@emi.fraunhofer.de

Finanziert von der Europäischen Union
NextGenerationEU
Gefördert durch:
Bundesministerium für Wirtschaft und Klimaschutz
aufgrund eines Beschlusses des Deutschen Bundestages

Photos: Ziyan Yang / stock.adobe.com, Fraunhofer EMI, Fraunhofer EMI (using Midjourney)

DigiTain general meeting: Developing vehicles sustainably

The DigiTain – Digitalization for Sustainability – research project addresses issues relating to the fully digital product development of sustainable electric drive architectures. Since the beginning of 2023, 26 funded and 2 associated partners from industry and science have been working on new methods for sustainability assessment during development.

Fraunhofer EMI is developing innovative solutions in various work packages:

- Safe design and integration of battery storage systems
- New recycling methods for CFRP hydrogen tanks
- Novel crash tests for battery cells
- Automation of life cycle assessment
- New experimental validation methods

Meeting of the consortium at Fraunhofer EMI
Around 90 members of the consortium met on January 18, 2024. The aim of the project is to integrate ecologically and economically sustainable criteria into the early phases of vehicle development.

Thermal runaway of pouch cells
Experimental investigation of the effect on polymer structures.

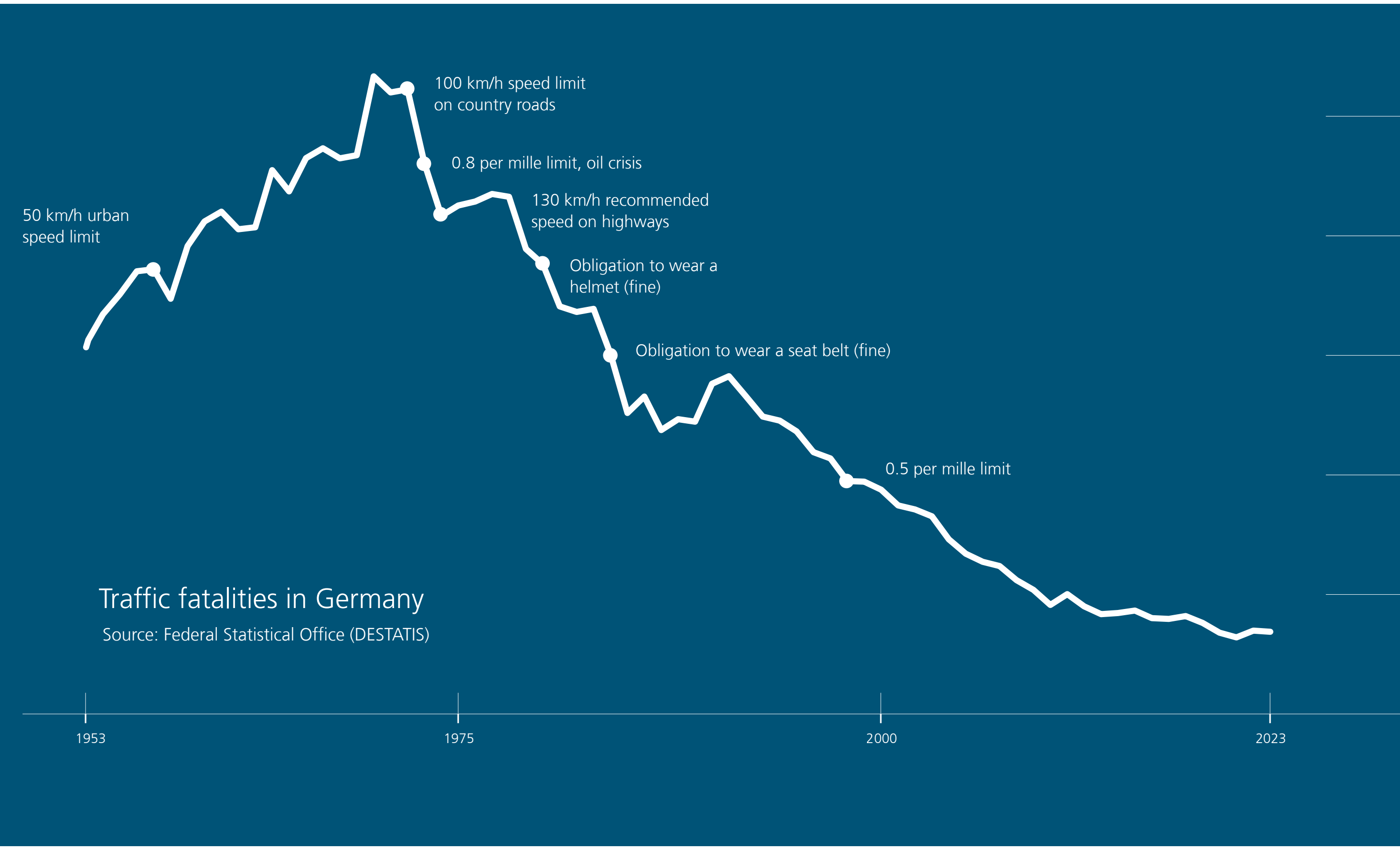
Safe battery housings made of polymers

Method development for virtual design against the consequences of thermal runaway

Experimental verification of the safety of battery housings is time-consuming and cost-intensive. Fraunhofer EMI is therefore working with the project partners Kautex Textron GmbH & Co. KG and Farasis Energy Europe GmbH to develop simulation methods for virtual housing design (SiKuBa project).

The main basis for these simulation methods are highly instrumented battery tests. In these tests, the thermal runaway is specifically induced in the laboratory.

The project is funded by the Federal Ministry for Economic Affairs and Climate Action (BMWK).



Vision Zero

Goal: no more traffic fatalities in Europe by 2050

The term Vision Zero was originally developed in the field of occupational safety. It states that no employees should be injured or killed in the workplace due to a lack of safety precautions. The principle was introduced by the Swedish parliament in 1997 in the form of the Road Traffic Safety Bill in order to improve road safety in Sweden.
In 2017, the EU Commission formulated Vision Zero as a paradigm shift and action plan for European road traffic. The aim is to have no more road deaths in Europe by 2050. The Federal Republic of Germany, like other EU member states, has committed to achieving this goal.

Business unit Automotive
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Photos: Fraunhofer EMI (3), Federal Statistical Office (DESTATIS)

BUSINESS UNIT Space

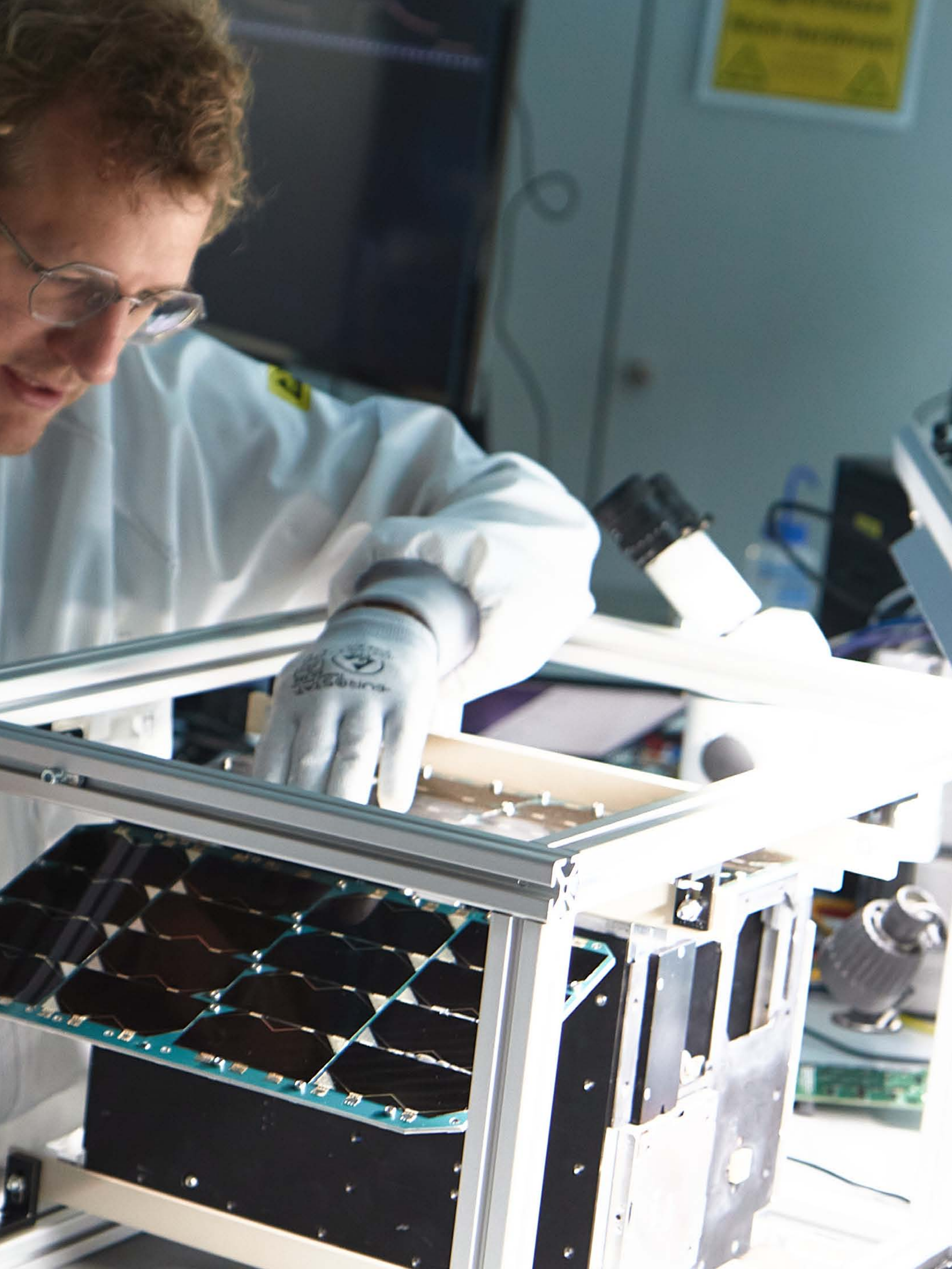
Business unit Space

Photo: Fraunhofer EMI

Small satellites – big performance

The “dwarfs” among satellites achieve great things: they detect wildfires, detect greenhouse gases, see clouds, measure sea temperatures, recognize vehicles ... and much more. On the following pages, you can find out how research is helping to turn them into an economic success model.

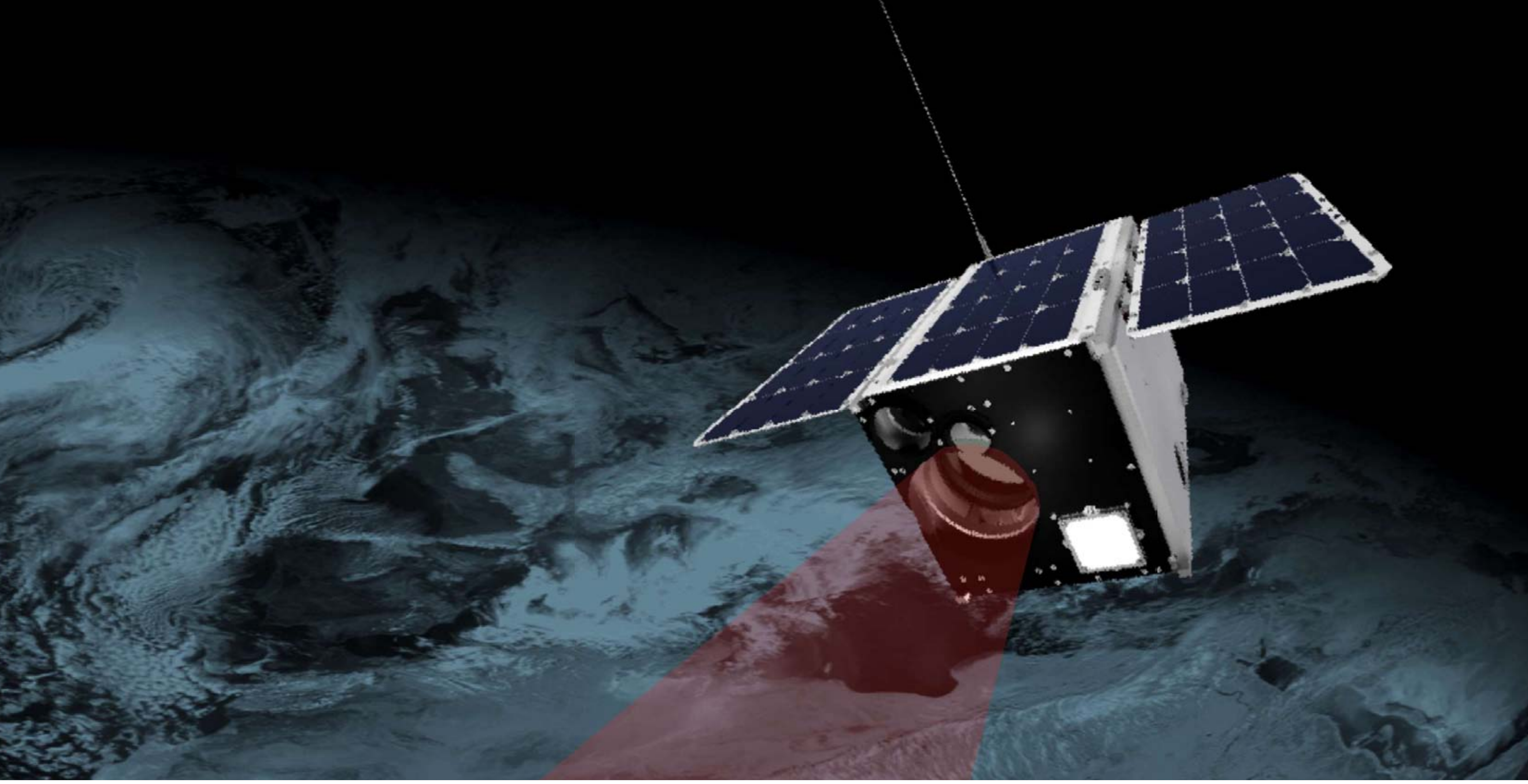
In the picture: Nanosatellite ERNST is being prepared for the thermal vacuum test, one of the most important environmental tests for simulating the flight of a satellite in low Earth orbit.



Driving innovation in space: small satellites as key technology

Space is increasingly being used commercially. This is demonstrated by the rapidly increasing number of satellites in low Earth orbits. The satellite constellations under construction are constituting a new infrastructure in space. Satellite technology is enabling new applications for business, governments and society. Small satellites are the key to this.

From **Prof. Dr. Frank Schäfer**



Small satellites are the key to new applications for business, governments and society. The illustration shows the 12U Cubesat ERNST from Fraunhofer EMI.

Photos: Fraunhofer EMI (using Midjourney), Fraunhofer EMI

NewSpace: Commercialization of space

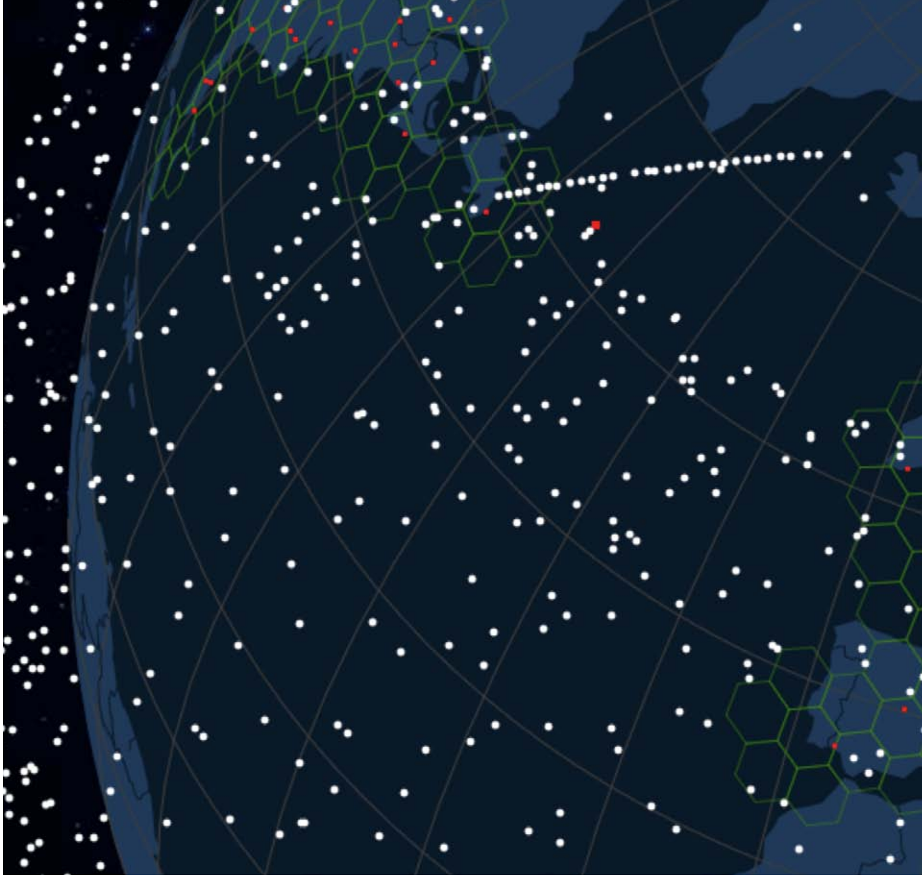
The increasing commercialization of space, which is summarized under the term NewSpace, can be impressively illustrated by the rising number of satellite launches. According to the United Nations Office for Outer Space Affairs, 586 satellites were put into orbit in 2019, while this figure rose to 2664 satellites in just 4 years. This corresponds to an average annual increase of 46 %. Remarkably, from the beginning of space travel until 2016, no more than 250 satellites were ever launched in one year. Of the satellites launched in 2023, 1935 belonged to the Starlink constellation of the US company SpaceX, which corresponds to around 73 % of all satellites launched. Around 80 % of all satellites were launched by the USA. For comparison: Germany launched 5 satellites in 2023. In the same period (2019 – 2023), the number of launches of launch vehicles worldwide rose from 102 to 223.

With around 5,000 operational satellites in low Earth orbits as of April 2024, Starlink currently dominates the market for high-speed internet from space. The economic potential in the area of telecommunications applications alone is enormous, as a recent report by the World Economic Forum from 2024 shows: with annual growth rates of projected at 4 %, especially in the areas of broadband internet, IoT, the integration of space and terrestrial mobile communication networks and direct-to-device (D2D) communications, other commercial players such as Oneweb, Amazon Kuiper and Rivada are entering the market.

Satellite constellations: Backbone of the emerging infrastructure in space

Satellite constellations can consist of hundreds or thousands of satellites. They represent the central pillar of a new space-based infrastructure that offers global coverage with rapid data availability, i.e. low latency times. The development of constellations is currently being driven in particular by the increasing demand for fast internet and digital networks, real-time Earth observation data and precise navigation. However, satellite constellations are also indispensable for research into the Earth system and for a better understanding of climate change.

The increasing integration between NewSpace companies and the non-space economy is creating new services and business models based on the new space infrastructure in many sectors, such as telecommunications, agriculture, mobility and logistics, disaster management, urban development, civil security and defense. The development of satellite constellations is a prerequisite for the emergence of these markets and therefore plays a key role for the economy, a sovereign state and society.



Distribution of the Starlink satellites in the upper hemisphere in March 2023. With a mass of approx. 300 kg, the first-generation Starlink satellites belong to the class of small satellites.

However, the commercial market for satellite constellation technology and the services it enables is currently dominated by a small number of economic players, mainly from the USA and China. According to the Federation of German Industries (BDI), Europe and Germany in particular are currently underrepresented in this booming global market.

Small satellites for setting up constellations: Highest system performance, minimum volume, low-cost production

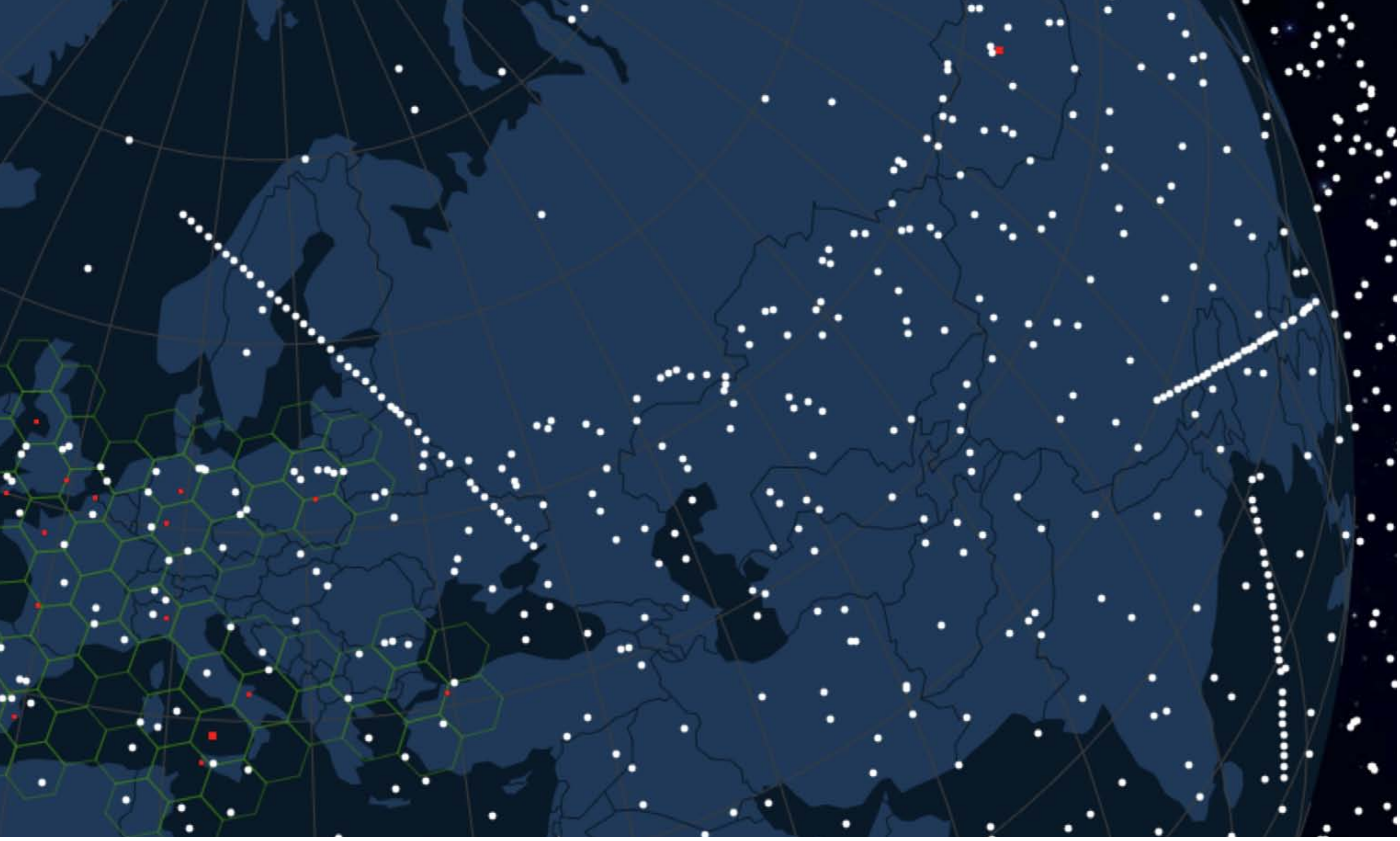
Small satellites play the decisive role in NewSpace for the construction of large satellite constellations. By definition, small satellites have a mass of up to 500 kg, with the following sub-classes: Minisats (100 - 500 kg), Microsats (10 - 100 kg), Nanosats (1 - 10 kg) and Picosats (0.1 - 1 kg). Significant technological innovations in miniaturization, manufacturing processes and the performance of relevant technologies have promoted the development of compact, autonomous and cost-effective small satellite systems. Small satellites can deliver high system performance with minimal volume. Expensive space components are being replaced – wherever possible – by reliable and powerful commercial off-the-shelf (COTS) components. The need to minimize costs due to the high quantities required is the driving force behind new production processes. Innovation cycles are becoming shorter and shorter.

Small satellites are drivers of innovation: two Microsats have flown to Mars to establish a communication link to Earth (Mars Cube One). A constellation of Minisats provides high-resolution optical images of the Earth with a resolution of 50 centimetres per pixel (Skysat). A constellation of Nanosats tracks ship movements worldwide with AIS and tracks aircraft with ADS-B (Lemur). Soon, microsatellites with thermal infrared cameras will help to reduce water consumption in agriculture (HiVE). Nanosatellites will soon demonstrate that rocket launches can be detected with high sensitivity worldwide (ERNST). The list goes on.

The demand for small satellites over the next few years is enormous. A market study by Euroconsult from 2023, for example, assumes that an annual average of 2610 small satellites will be required by 2032. Most of these small satellites will be part of near-Earth constellations in LEO and will mainly be used for commercial applications in the fields of Earth observation, telecommunications and navigation.

Applied research as the key to innovation in small satellite technologies

Intensive research and development of intelligent solutions for miniaturized satellite bus systems, payload technologies and advanced software concepts are required to overcome the inherent limitations of small satellites.



Due to the interdisciplinary nature of these technical challenges, relevant innovations can only be achieved through the coordinated cooperation of different disciplines. This is an exciting field of research for the Fraunhofer-Gesellschaft with its broad thematic focus. With its application-oriented research, the Fraunhofer-Gesellschaft not only offers the ideal structure for this task, but also has the necessary excellence in all relevant disciplines with the numerous institutes of the Fraunhofer AVIATION & SPACE Alliance.

These include the available modern product development methods and manufacturing processes, above all additive manufacturing: it enables the future-oriented production of complex and robust components, digitally, individually, quickly and cost-efficient. Additive manufacturing processes also enable resource-saving and therefore sustainable production, an aspect that is playing an increasingly important role in the space sector. In addition to coating processes to increase the robustness of surfaces, for example for optics or antennas, or for the magnetic shielding of sensitive instruments, completely new possibilities are opening up for space systems in the area of multifunctional surfaces. For example, by integrating antennas into non-conductive structural elements, the compactness of satellites can be increased while at the same time reducing the complexity of the antenna system. Manufacturing costs are also reduced. Deployable structures and payload components are needed, for example, to realize high-resolution and adaptive optics on small satellites.

Photos: satellitemap.space, Fraunhofer EMI

Satellite constellations are the central pillar of a new space-based infrastructure with which global coverage and rapid data availability can be achieved. The conceptual illustration shows an Earth observation satellite and the ground track of the fictitious camera.

Fraunhofer offers expertise and manufacturing processes along the entire value chain

With the large amounts of data generated in multi- and hyperspectral Earth observation and for communication applications, ever greater demands are being placed on the computing power of data processing systems. The most promising approaches to overcoming the current limitations of small satellites include powerful onboard data processing systems that also allow AI methods to be used on the satellite. This makes data available to applications almost in real time and link capacities can be used efficiently. The ability to reconfigure data processing systems in flight is becoming increasingly essential so that future user requirements can be implemented directly on board the satellite.

Increased automation in testing and qualification is also necessary to save development time and for quality control in series production.

With the available know-how in the field of manufacturing processes and experimental, automatable series production as well as the innovative technologies in the field of digital systems and payload technologies, Fraunhofer can cover the needs of industry along the entire value chain.

Examples of demonstrators at system level that are being researched and developed at EMI, also with the participation of Fraunhofer and industrial partners, are:

- The LisR thermal infrared payload demonstrated on the International Space Station ISS in 2023.
- The ERNST small satellite to be launched in 2024.
- A new satellite system concept for applications in extremely low Earth orbits, so-called VLEOs – Very Low Earth Orbit.

Fraunhofer has extensive system know-how in the field of space technology to strengthen the competitiveness of industry and to create new business models. This enables German and European companies to participate more strongly and more quickly in the future market for space technologies and products.

Current research at Fraunhofer EMI

Small satellite system technologies

12U CubeSat ERNST, funded by the Bundeswehr.

VLEO-Demonstrator, funded by the Bavarian State Ministry of Economic Affairs, Regional Development and Energy.

Scientific payload for Earth observation in the thermal infrared

Longwave infrared sensing demonstratoR (LisR), funded by the Federal Ministry of Economics and Climate Protection.

Data processing technologies

EMI Data Processing Unit (DPU), funded by industrial contracts, the Bundeswehr and the Federal Ministry of Defence (BMVg).

Final touches before delivery: nanosatellite ERNST to be launched into space in summer 2024

ERNST's journey begins

First research satellite for Bundeswehr applications about to be launched

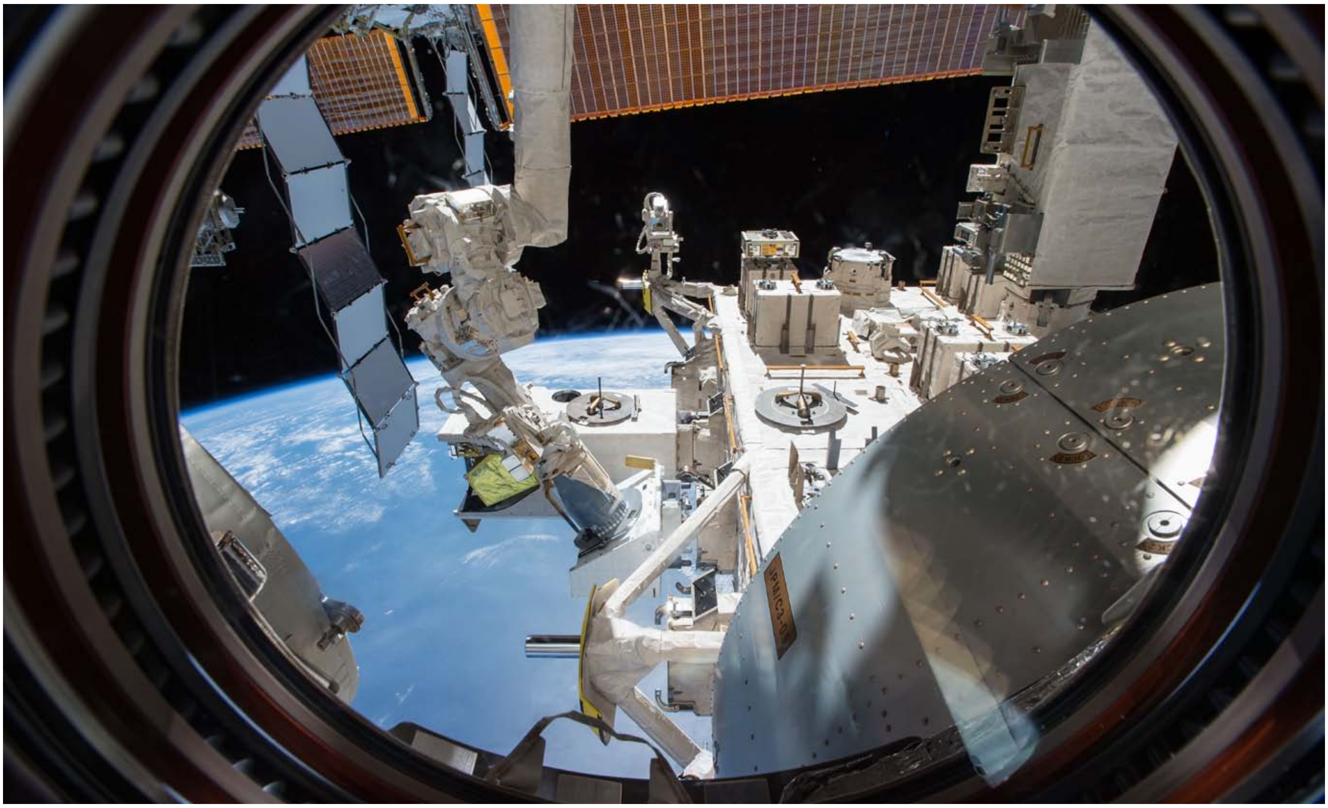
The mission of the experimental small satellite ERNST is about to be launched in the summer of 2024. ERNST is a powerful 12UXL-CubeSat, a technology demonstrator that accommodates several technological innovations in a compact volume of 24 × 25 × 37 cm³, including a generatively designed and manufactured optical bench with an integrated 3D radiator and an autonomous de-orbit brake sail for the sustainable use of the space environment. These include a generatively designed and manufactured optical bench with an integrated 3D radiator and an autonomous de-orbit drag sail for the sustainable use of the space environment. At the heart of the satellite is a cryogenically cooled infrared camera that will demonstrate methods of satellite-based missile early warning and tracking. This detection of a threat immediately after launch of the missile is essential for taking defensive measures to counter it.

The technology development work on the flight model of the ERNST satellite was successfully completed in 2023. The satellite was transferred from a so-called flat-sat configuration, in which the satellite components are operated in a network on a test basis but are easily accessible for modifications, to the final integration state. After calibrating the sensors, we successfully demonstrated in final acceptance tests that the satellite can withstand the loads during rocket launch and in the orbital environment. By procuring a commercial satellite launch service, EMI was also able to ensure a timely launch in 2024 after repeated delays in the original launch program. The completed ERNST has been in the care of the launch service provider since the end of April 2024. As planned, ERNST will be integrated on a Falcon 9 rocket after a final check-out by EMI employees at the end of May 2024 and begin its journey into orbit.

Project "ERNST"
Dr. Martin Schimmerohn,
martin.schimmerohn@emi.fraunhofer.de,

Compact but powerful: ERNST, the experimental nanosatellite.

Photos: Fraunhofer EMI (2)



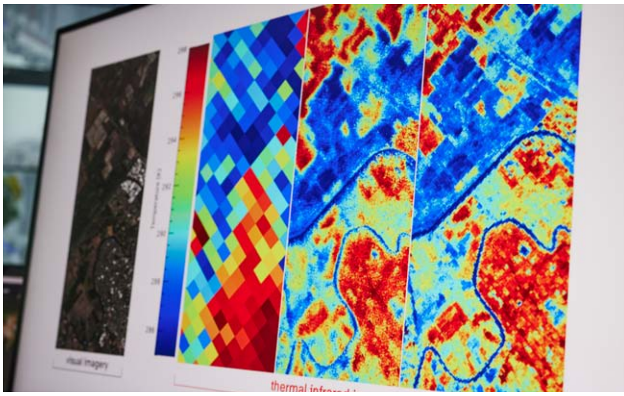
Assembly on the ISS: The NREP platform is assembled on the outside of the Japanese research module of the ISS using a robotic arm.

Sustainable water use through satellite technology

How the "Longwave infrared sensing demonstratoR LisR" supports agriculture in the efficient use of water resources.

Water is a scarce commodity and will become even more precious in future due to the growing world population. It is therefore essential to no longer irrigate plants on the basis of estimates, but rather in a targeted manner according to their respective needs.
This is made possible by a new type of satellite technology that detects heat radiation from orbit and thus physically measures the land temperature. This allows conclusions to be drawn about the irrigation status of the plants. Led by the founding idea of constellr GmbH, researchers from the Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institut, EMI, the Fraunhofer Institute for Applied Optics and Precision Engineering IOF and the companies constellr GmbH and SPACEOPTIX GmbH – both spin-offs from these institutes – developed the infrared camera "LisR", short for "Longwave infrared sensing demonstratoR". LisR was

Back on Earth: LisR after a successful mission in space.
The technology has enormous potential. The camera signals make it possible to detect over- or under-irrigation and take targeted measures.



Honored: Winner of the Fraunhofer Prize "Technology for People and their Environment" 2023.

successfully tested on the International Space Station ISS in 2022. Based on the findings of the LisR mission, constellr is planning to launch its own satellites into orbit. With the help of the satellite constellation, it would then be possible to save 180 billion tons of water and 94 million tons of CO_2 and increase the global harvest by up to four percent from 2026.

The jury was impressed by the outstanding collaboration between several institutes and two spin-offs to record the water content in plants and the surface temperature from space worldwide.

"LisR" project
Clemens Horch, clemens.horch@emi.fraunhofer.de

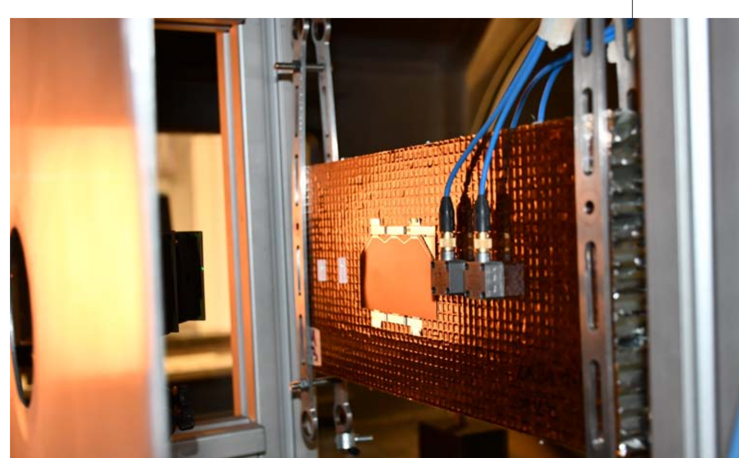
Photos: NASA, Piotr Banczerowski/Fraunhofer (2), Fraunhofer EMI (2)

Impact research at orbital velocities

Verification of new space technology on the Space Gun

In 2023, Fraunhofer EMI used its unique accelerator facilities to conduct numerous experiments to investigate the effects on space components. For Airbus DS, the institute investigated the robustness of new thin-film solar generators and external cable bundles against the impact of micrometeoroids and space debris particles at orbital velocities.

Fraunhofer EMI supported the University of the German Armed Forces in Munich with experiments to develop sensors to detect these high-speed impacts. To this end, the characteristics of the vibrations during the impact on external satellite components were investigated, which can be used to detect and localize the impact events.



Hypervelocity Impact Testing
Robin Putzar, robin.putzar@emi.fraunhofer.de

Space

Highest on-board computing power for small satellites

Fraunhofer EMI supplies the data processing system for the upcoming HiVE satellite mission of constellr GmbH.

HiVE mission: a satellite constellation project for precise Earth observation

Following on from the successful LisR mission, constellr GmbH is currently preparing the "High precision Versatile Ecosphere" (HiVE) mission. The constellation of micro-satellites will begin with the launch of the first satellite at the end of 2024. 30 satellites are expected to image the Earth in the visible and near-infrared spectrum and, in particular, in the thermal infrared spectrum by 2032. Constellr will offer a land-surface temperature (LST) data product with a ground resolution of 30 m per pixel based on the data obtained with HiVE. The aim is to improve the analysis of plant growth, water use and carbon cycles for users in the agricultural sector.

Constellr is being supported in the development of the HiVE satellites by a consortium consisting of OHB System AG, Kongsberg NanoAvionics and Fraunhofer EMI. OHB is supplying the multispectral payload, while NanoAvionics is responsible for the satellite platform. The work is being funded by the European Space Agency ESA.

Data processing and redundancy

In addition to the patented technology developed at Fraunhofer EMI concerning a new radiometric calibration method, EMI's expertise in the field of on-board data processing is also being used in the HiVE mission. EMI is contributing its Data Processing Unit (DPU) as the central computer for the payload of the HiVE satellites.

The DPU is a compact system based on low-cost commercial off-the-shelf (COTS) electronic components. All image data is pre-processed by the DPU and temporarily stored there until it is transmitted to Earth. The DPU is also responsible for controlling and monitoring the payload. The DPU software can be reconfigured during the mission and is designed for a high degree of automation on the one hand and the greatest possible flexibility in operation on the other.

The DPU for HiVE is based on the successful development for the LisR mission. In order to meet the high requirements of a commercial mission, the design of the DPU has been revised and is now fully redundant. All internal components are now available at least twice in order to be able to switch to the redundant unit in the event of a fault. The redundancy of the hardware is supplemented by software measures to further increase reliability. For example, the entire software of the DPU is stored in a total of 18 copies on six different memory modules.

Spin-off writes success story

As part of the HiVE mission, EMI's DPU was also qualified for the first time with regard to vibrations and thermal vacuum environment in accordance with the European space standards ECCS. The necessary qualification tests were carried out in EMI's satellite laboratory. The first flight model of the data processing unit for HiVE was delivered to constellr at the beginning of 2024 and is currently being integrated into the satellite. Work then began at EMI on the subsequent DPU models for the HiVE constellation.

The success story of constellr as an EMI spin-off is about to reach the next stage. Fraunhofer EMI is proud to be able to continue to support this development by transfer of Fraunhofer technology.

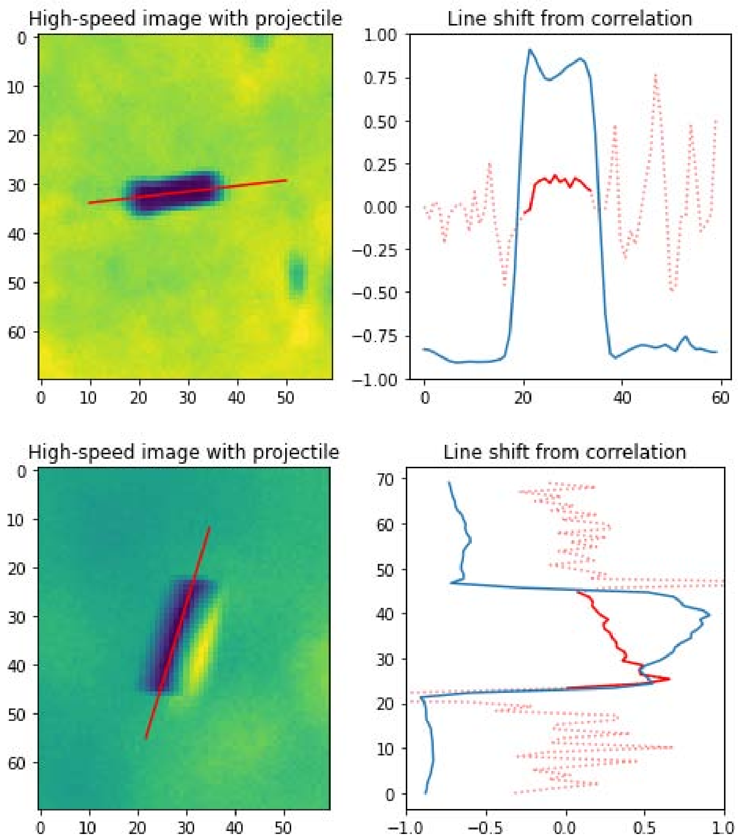
Project "HiVE DPU"

Clemens Horch, clemens.horch@emi.fraunhofer.de

Shape effects during hypervelocity impact

Experiments with cylindrical impactors

The spherical cow is a common metaphor for simplified scientific models that allow simpler modeling but obviously do not reflect reality as well. Experimental data that has been conducted almost exclusively with spherical objects is also used to analyze the risk posed to space systems by high-speed impacts from space debris objects. This approach is of a practical nature, as spheres are easier to accelerate in two-stage light-gas accelerators and are considered as an idealized mean value. As with the cow, assuming a spherical shape for space debris is a gross oversimplification. In a project for the European Space Agency ESA, EMI is currently researching the effects of using non-spherical impactors. To this end, experiments were carried out in 2023 with various cylindrical shapes, from disks to rods, which are currently being followed by extensive numerical simulations.



Investigating the effects of non-spherical impactors in space: rod and disk at 7 km/s on the Space Gun.

Project “Sheers”
Dr. Martin Schimmerohn,
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Business unit Space
Prof. Dr. Frank Schäfer, frank.schaefer@emi.fraunhofer.de
→ emi.fraunhofer.de/raumfahrt

Photos: Fraunhofer EMI (4)

Business unit Aviation

How dangerous are cell phones and laptops in airplanes?

Fraunhofer and Airbus are investigating the risks of lithium batteries in airplanes. To this end, various laptops, tablets and smartphones were heated in a controlled manner at Fraunhofer EMI's battery test center in order to collect data for investigating the spread of smoke. This data is used to simulate the spread of fire and smoke in realistic aircraft environments.

Read more in the "Loki-PED" project report.

Photo: Irina Schmidt / stock.adobe.com

On the way to sustainable and competitive aviation

Aviation plays an important role in global passenger and freight transport. At the same time, it is responsible for around three percent of global CO_2 emissions. This is relatively low compared to other sectors such as the energy industry or road transport.

Unfortunately, it is expected that CO_2 emissions from the aviation industry will continue to rise in the coming years due to the increase in air traffic.

From **Dr. Michael May**

Future-proof aviation
Innovations in technology and design can make aircraft more environmentally friendly while meeting the growing demand for air transport.

Photo: Pascal Meier / unsplash.com

Long-term goals for sustainable and competitive aviation

Flightpath 2050, a strategic concept of the European Commission, defines long-term goals and a vision for sustainable and competitive aviation by 2050. This concept lays the foundation for the development of technologies, processes and measures to reduce the environmental impact of aviation. The Flightpath 2050 targets include reducing CO_2 emissions by 75 % per passenger kilometer by 2050, reducing NO_x emissions by 90 % per passenger kilometer by 2050 and reducing noise emissions by 65 %, in each case compared to the year 2000. The aviation industry is conducting intensive research into improved aerodynamics, lighter materials, more efficient engines and new propulsion concepts in order to achieve the Flightpath 2050 targets. Sustainable aviation fuels (SAF), hydrogen propulsion (direct combustion and fuel cells) and battery-electric flying play a special role in this context.

New fuels and energy sources

SAF is an alternative fuel that is produced from renewable sources and helps to reduce the CO_2 footprint of flights. SAF can be used in conventional aircraft without major modifications and blends easily with conventional kerosene. This enables a gradual introduction of sustainable aviation fuel into the aviation industry while reducing CO_2 emissions. However, there are still challenges to the large-scale introduction of SAF. These include limited availability and higher costs compared to conventional kerosene.

Hydrogen as a source of hope

Hydrogen is considered a promising energy source for the aviation industry to reduce CO_2 emissions and enable a more climate-friendly future. Hydrogen can be used in both fuel cells and combustion engines to generate electrical energy and power aircraft. However, there are also challenges in the use of hydrogen in aviation, as there is currently still a lack of hydrogen infrastructure. Extensive investments in hydrogen production, storage and distribution would have to be made in order to create sufficient infrastructure for the use of hydrogen in aviation. In addition, hydrogen requires a higher volume compared to conventional aviation fuels, which reduces the number of passengers per aircraft. As a result, hydrogen-powered aircraft will initially only be able to be used on short or medium-haul routes. Another aspect to consider when looking at hydrogen is safety. Hydrogen is highly flammable and requires special safety precautions. The development of safe storage methods and systems is crucial to ensure the safety of passengers and aircrew. This is where EMI scientists can bring their years of expertise from other industries to the aviation industry.

Innovative propulsion systems

All-electric, battery-powered propulsion systems are considered the most promising approach to making aviation more climate-friendly. Electric drives have the potential to operate aircraft completely emission-free. However, there are still challenges to overcome, such as the limited energy density of batteries, the range, the charging infrastructure and the weight of the batteries.

Aviation

Despite the challenges, electric drives are expected to play an increasingly important role in the aviation industry in the coming years. The continuous development and research in this area, which is also being carried out at Fraunhofer EMI, among others, will help to further improve the efficiency and performance of electric drives and thus make a significant contribution to achieving the climate targets in aviation.

Diverse approaches

In general, each of the three routes (SAF, hydrogen, battery electric) seems to have a place in future aviation, as each technology will be optimal for a specific area of application. For example, it can be assumed that SAF will prevail on long-haul flights; hydrogen has great potential on short and medium-haul flights; battery-powered, all-electric concepts will be successful on short-haul flights.
In 2023, the major European research project Clean Aviation was launched, which aims to pave the way for climate-neutral aviation. In addition to many other partners, scientists from Fraunhofer EMI, are also involved in this project to get closer to the goal of climate-neutral aviation.

Current research at Fraunhofer EMI

Ultra-efficient wing structures
UpWing project

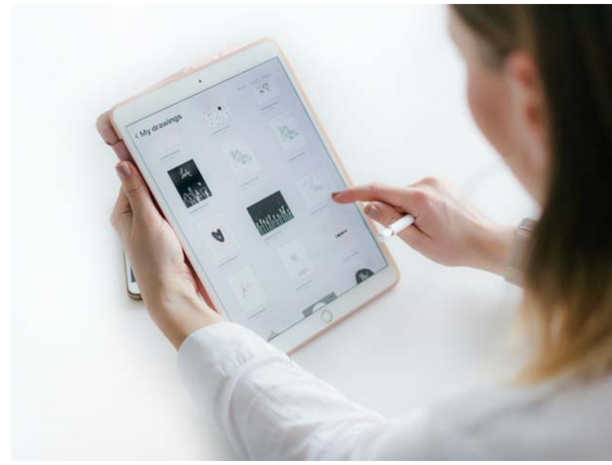
Part of the EU's "Clean Aviation" research program

Battery safety in the cabin
LOKI-PED project

Funded by EASA – European Union Aviation Safety Agency

Battery safety
BATTcopter project

Safe use of laptops, tablets and smartphones in airplanes



Problems with lithium-ion batteries in airplanes are relatively rare. But when they do occur, they can have serious consequences – including fire or explosions.

As part of the "LOKI-PED" project (Lithium batteries in pOrtable electronic devices – risK of flre and smoke), Fraunhofer EMI and Fraunhofer IBP are working together with Airbus.

The smoke and fire risks associated with lithium batteries in portable electronic devices (PEDs) in cabins and cockpits are being investigated and evaluated. The project is supported by the European Union Aviation Safety Agency (EASA). It is funded by the European Union's Horizon Europe research framework program.

Last year, the hazards posed by PEDs during thermal runaway were characterized. To this end, various PEDs such as laptops, tablets, smartphones and power tool batteries were tested and safely heated at the TEVLIB battery test center at Fraunhofer EMI in Efringen-Kirchen. Optical and thermal cameras as well as pressure, temperature and flow sensors were used to ensure maximum information and high-quality test results. This data is used to derive artificial smoke sources for our colleagues at Fraunhofer IBP. They carry out the experimental studies on smoke propagation in a realistically ventilated A321 cabin in the flight laboratory in Holzkirchen.

Simulation and real fire tests
Based on these validation tests, the Fraunhofer IBP zone model can be used to carry out numerical simulations of any aircraft cabin as well as parameter studies. This allows to estimate the effects of smoke propagation on individual passengers and the safe operation of the flight. In addition, fire tests are carried out with real PEDs during thermal runaway in a realistic cabin environment. Fraunhofer IBP and EMI are combining their expertise in the areas of cabin ventilation and battery fire for this purpose.

Final risk assessment
All results are incorporated into the subsequent risk assessment, which is carried out by the Hazard and Risk Analysis Group at Fraunhofer EMI. Experts from Airbus support all aspects of the project with their expertise in the areas of regulations, aircraft ventilation, battery fire and fire safety.

The project team is in close contact with members of the aviation industry. An exchange on the topic of thermal runaway of batteries in the cabin and cockpit took place as part of a panel discussion at the IATA World Safety & Operations Conference 2023.

Project LOKI-PED
Simon Holz,
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Photos: Douglas Bagg / unsplash.com, Marek Levak / unsplash.com, Fraunhofer EMI (using Midjourney)

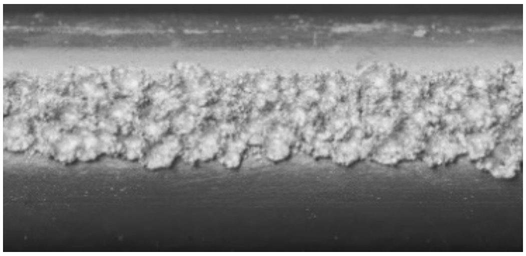
Aviation

Ultra-efficient wing structures

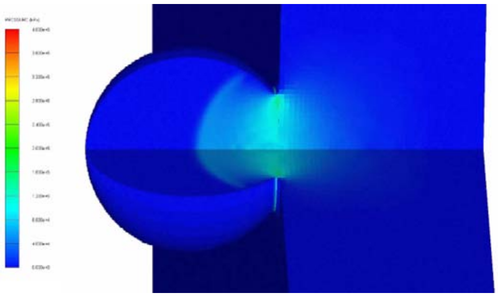
Fraunhofer EMI is researching how new wing coatings can increase resistance to rain, sand and hail damage while reducing fuel consumption.

The UP Wing (Ultra Performance Wing) project is part of the "Clean Aviation" research program funded by the European Union. In UP Wing, an interdisciplinary consortium of industry, research institutes and universities is developing important basic technologies for wing concepts with maximum performance for short and medium-haul aircraft. The aim is to significantly reduce fuel consumption. Together with IFAM, which is responsible for Fraunhofer, EMI is involved in two sub-projects in which the resistance of new coatings to rain and sand erosion and the robustness of a new wing structure against hailstorms are being investigated. In the area of rain and sand erosion, EMI is using its expertise in the numerical simulation of impact processes and fluid-structure coupling. Hail impact is to be investigated both in simulation and in impact tests on demonstrator structures.

The simulation methodology is currently being expanded in order to be able to simulate the effect of a larger number of impacts. The formation of craters requires a fluid-structure interaction for strongly changing surfaces, which can be realized particularly efficiently for three-dimensional simulations in the EMI software APOLLO by coupling it with a structure solver. This allows the amplification effect caused by the change in geometry to be taken into account. Such models can be used to investigate the influences of material properties and coatings in detail. These investigations support the development of new, fuel-saving and durable coatings.



Extreme rain erosion on an aluminum profile
Calibration test for an erosion test facility, carried out by R&D Test Systems, Hinnerup, Denmark. The speed at the end of the profile was 160 m/s, test time 10 hours.



Simulation of the impact of a drop of water with a diameter of 2 mm and an initial velocity of 225 m/s on an aluminum sheet in a sectional view. A shock wave propagates into the droplet. Pressure peaks of over 300 MPa occur briefly and locally at the contact surface.

Project "UP Wing"
Dr.-Ing. Martin Sauer,
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2023 in retrospect

Brussels: Towards a more environmentally friendly aviation

Michael May took part in a one-hour panel discussion as part of the event "The research road to net-zero industry". The topic was: "Navigating towards a more sustainable future for aviation". On a large stage, he discussed the future of sustainable and environmentally friendly aviation with representatives from industry and the EU Commission.

Round table from politics, industry and research
Michael May (Fraunhofer EMI), Damien Meadows (DG CLIMA, EU Commission), Riccardo Procacci (CEO Avio Aero), Rosalinde van der Vlies (DG RTD, EU Commission), Brandon Mitchener (moderator)

AIAA SciTech in Orlando

In January 2024, the American Institute of Aeronautics and Astronautics (AIAA) hosted the AIAA SciTech Forum in Orlando, Florida. The SciTech Forum is the world's largest scientific meeting in the field of aerospace technology. EMI scientists presented a paper on simulating the collision of drones with helicopters and, as part of their contribution, drew attention to possible dangers to aviation from unintentional collisions between drones and helicopters.

Paris Air Show: Nanosatellite and additively manufactured component

At the last Paris Air Show (June 19-25, 2023), Fraunhofer EMI participated in a joint booth of the Fraunhofer AVIATION and SPACE Alliance and presented the nanosatellite ERNST as well as a 3D-printed metallic structural component for a cargo door, which was developed in cooperation with SAAB as part of Clean Sky 2.

Business unit Aviation
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Photos: Ross Rarmly / unsplash.com, Fraunhofer EMI (3)

Sustainability Center Freiburg

Recovery of carbon fibers

Previous recycling processes for fiber composites shred the material and thus lead to downcycling of the material.

Carbon fibers can now be recovered without significant shortening using an innovative separation process.

The project is one of currently four national projects funded by the Sustainability Center.

Photo: Fraunhofer EMI

Applying sustainability research

LEISTUNGSZENTRUM NACHHALTIGKEIT FREIBURG

The Sustainability Center (»Leistungszentrum Nachhaltigkeit« / LZN) carries out research and promotes projects in the fields of sustainable materials, energy systems, resilience and ecological and social transformation.

Joint research for Sustainabilty
The LZN is a cooperation between the five Freiburg Fraunhofer Institutes EMI, IAF, IPM, ISE and IWM, the University of Freiburg and other non-university research institutions and partners. The aim is to explore solutions for a sustainable future in joint research projects and put them into practice. To this end, the LZN cooperates with companies, associations and other important regional partners.

Transfer of technologies and innovations
The LZN brings technologies and innovations into practice in a variety of ways. These transfer paths include technology licensing, contract research, spin-offs and science communication. They correspond to the Fraunhofer transfer paths.

Start-up support for sustainable and innovative ideas
The LZN is a longstanding partner in the local and regional start-up ecosystem. It links science with entrepreneurial ideas. It also offers its own annual funding format to support Fraunhofer employees who are interested in setting up their own business. The aim is to bring sustainable, technological ideas into application and to strengthen Freiburg as an innovation location for founders.

Development of more efficient solar cells at INATECH: research into new approaches based on completely different materials than previous cells.

INATECH: developing sustainable solutions for the future today

Five Fraunhofer institutes, the University of Freiburg and a common goal: to establish sustainability as a guiding principle in the development of technical systems.

Engineering science for more sustainability
The Department for Sustainable Systems Engineering (INATECH) is the scientific core of the LZN. Its scientists research and develop sustainable engineering solutions.

Focus on the needs of current and future generations
Together with research partners from the public sector and the industry, INATECH is researching methods, models, materials, technologies and demonstrators. It develops sustainable technical systems that meet needs with the smallest possible ecological footprint.

From basic research to industrial application
The cooperation between Fraunhofer and the university pools scientific and technological expertise, covering the entire spectrum from basic research to industrial application. INATECH is a department at the Faculty of Engineering at the University of Freiburg.

Cooperation between Fraunhofer and the University of Freiburg: INATECH is located on the campus of the Faculty of Engineering. 260 students are enrolled in the Bachelor's and Master's degree programs in "Sustainable Systems Engineering".

Photos: INATECH / University of Freiburg (2)

Sustainability Center Freiburg

Research projects at the LZN

Use and recycle hydrogen pressure vessels efficiently

Project WEiTeR – Strategy for hydrogen containers at end-of-use: from extended use to high-quality carbon fiber tape recovery

Hydrogen as an energy vector is a central component of the strategy to reduce CO_2 emissions in Germany. Particularly in the traffic and transportation sectors, this energy carrier offers the possibility of replacing fossil fuels. In terms of hydrogen storage, carbon-fiber-reinforced pressure vessels (CFRP tanks) are currently state of the art. Due to the energy-intensive manufacturing process of carbon fibers, a sustainable strategy for the end-of-use of hydrogen tanks must already be developed today.

The aim of the WEiteR project is to establish a Freiburg competence center for the evaluation of CFRP hydrogen tanks during operation and at end-of-use. Fraunhofer EMI and IWM as well as INATECH are involved in this project. As part of the project, solutions for extending the service life, reuse and high-quality recovery of the embedded carbon fibers – taking into account the aging of the materials used – are being developed and made available to industry.

During the service life, innovative methods for tracking and predicting the material properties are being developed based on monitoring the tanks. Depending on the scenario, this should enable an extension of the lifespan or qualification for a different application.

New recycling process

In addition, an innovative peel process for recovering the carbon fiber tapes without significantly shortening the fibers is being investigated and numerically modelled. This strategy differs significantly from current fiber composite recycling processes, which systematically include a shredding stage and thus lead to downcycling of the material. In contrast, the project results have shown that under suitable thermo-mechanical peeling conditions, the continuous fiber reinforced tapes can be recovered with retained mechanical properties. Accordingly, after recycling, they are available for a reuse in highly demanding applications.

High quality recovery process: the innovative peeling process enables the recoverey of preserved continuous fiber tapes. Above, a new carbon fiber tape, below a tape after peeling-based recycling.

Photos: Fraunhofer EMI (2), Fraunhofer EMI (using Midjourney)

Monitoring of critical underwater infrastructure

Project CoLiBri – Collaborative LiDAR to Monitor Infrastructure in the Water and at the Shoreline

Critical infrastructure is fundamental to ensure the safety and existence of our society. It must therefore be continuously tested and monitored.

In order to jointly generate scientific added value, researchers from the five Freiburg Fraunhofer Institutes work together with international cooperation partners in the LZN's international projects. Fraunhofer IPM is working with the Finnish Geospatial Research Institute FGI on a particularly compact sensor platform for laser-based inspection of critical underwater infrastructure such as offshore wind turbines.

Efficient monitoring

As part of the project, a core sensor module is being integrated into both an underwater scanner and a lightweight, airborne drone scanner. The systems will also be expanded to include a navigation and positioning solution and supplemented by comprehensive processing and evaluation software.

This creates a standardized process for simple, cost-effective and efficient monitoring. At the same time, other areas also benefit from the technology: cartography, coastal protection, flood protection, inspection, offshore construction and hydrology.

2023 in retrospect

Science Day with Züblin

The Science Day with the LZN involves an individually tailored, very specific approach to companies. Relevant questions and experts are identified in advance. In April 2023, a Science Day was held with the company Züblin. Here, INATECH representatives were able to discuss their expertise in the field of circularity engineering on the topic of sustainable construction with representatives from Züblin.

Innovation Bar: support for Freiburg's start-up scene

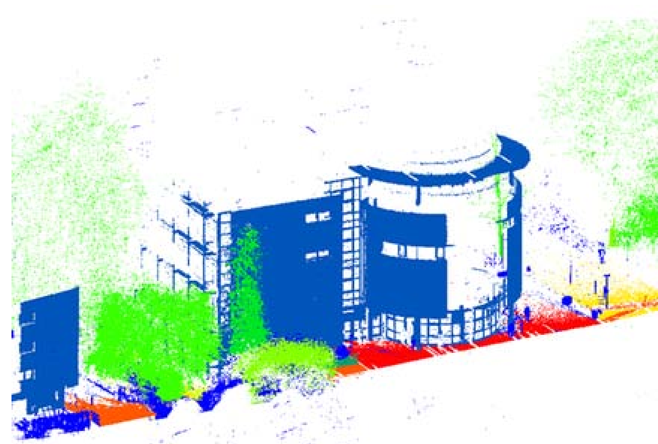
The Innovation Bar is a yearly event for young scientits interested in founding a company. The Sustainability Center and its cooperation partners BadenCampus, Grünhof, founders' office of the University of Freiburg and Startinsland / City of Freiburg provide information on support as well as funding opportunities for young researchers willing to start their own company.

Since 2019, a total of six start-ups have been supported, including the first spin-off from Fraunhofer EMI: constellr. Using its own space infrastructure, constellr is a leader in measuring water, temperature and carbon on the Earth's surface. The data is used to assess the health of vegetation and soil. This enables informed decisions to be made on food and water security.

MobiLab

In June, the LZN took part in the MobiLab Roadshow together with the University of Freiburg and Freiburg's Fraunhofer institutes. The MobiLab is a Tinyhouse designed as a participatory laboratory that makes cutting-edge research on sustainability in the Upper Rhine region visible in a roadshow on a Freiburg square.

The results of the joint project I4C – Intelligence for Cities were presented and made accessible to the general public: an interactive climate map of Freiburg showed the effects of climate change on our own doorstep.



Pop-up DATEN:RAUM:FREIBURG

DATEN:RAUM:FREIBURG - smart and digital city of Freiburg - was the titel of an exhibition organized by the city of Freiburg, which enabled exchange and networking with stakeholders from urban society and representatives of local authorities. The LZN presented the I4C-Intelligence for Cities project. In this project, urban geometry data as well as climate and weather data are processed using artificial intelligence (AI) methods in order to enable improved climate adaptation for cities.

Sustainability Talks at the Faculty of Engineering

The LZN and INATECH present the Sustainability Talks every winter semester. It is an interdisciplinary lecture series in which renowned scientists from various areas of sustainability give talks.
(Archive image: Prof. Dr. Ernst Ulrich von Weizsäcker)

Comprehensive information on the lecture series:
→ www.inatech.de/talks

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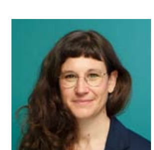
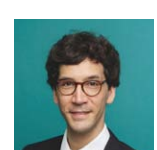
Dr. Juri Lienert, juri.lienert@emi.fraunhofer.de
→ www.leistungszentrum-nachhaltigkeit.de





Photos: Fraunhofer EMI (using Midjourney), LZN, I4C, LZN, Andree Kaiser

PREPARE PROJECT

Improved diagnostics in cancer detection and therapy

Computed tomography (CT) based on X-rays plays a central role in cancer detection. Unfortunately, the procedure itself can pose a health risk due to the high radiation exposure. An innovative approach opens up new possibilities by supplementing it with harmless radar radiation.

Imaging techniques have become indispensable in medicine for the diagnosis of diseases, but also for the monitoring of treatments. Computed tomography (CT) using X-rays plays a central role in the diagnosis of cancer. However, the procedure also has the disadvantage of posing a health risk itself.

Radar as a new technique

It is therefore advisable to supplement pure X-rays with other imaging techniques. Radar imaging also provides 3D data. The process is already standard in security applications, but in the medical field it is an outsider, despite being harmless to health.

The challenge for medical applications is to achieve a sufficiently high resolution. Compared to other methods, however, it offers the possibility of deriving direct material information.

The benefits of mammography in the early detection of breast cancer outweigh the risk of radiation exposure. Nevertheless, the exposure during an examination is around a quarter of the annual basic radiation. A technique co-developed at Fraunhofer EMI is intended to help reduce radiation exposure.

The aim of "Multi-Med" is to demonstrate the beneficial medical use of the combination of X-ray and radar CT. To this end, methods for the co-registration of imaging systems are being developed in order to harmonize the radar data with the X-ray data. The radar reconstruction algorithm will be expanded and the resolution and image quality will be increased using a-priori information. Hand in hand with this, the X-ray CT reconstruction is extended by the material-specific information obtained with radar, thus developing a multimodal CT algorithm to increase the quality and information density of the 3D data, reduce artifacts and lower the radiation dose introduced. In order to demonstrate the capabilities of the multimodal system, specific measurement phantoms are being developed that produce realistic signals on both measurement modalities and enable reproducible validation of the methods without having to work with real tissue. The final result is a multimodal laboratory system that demonstrates the fusion of the two imaging modalities.

What is a PREPARE project?

PREPARE projects are used for cross-institute, advanced preliminary research in preparation for new business areas. The aim is to lay the foundations for a longer-term alliance between the institutes. The funding amount for collaborative research projects is between 1.5 and 3.5 million euros with a maximum project duration of 3 years. Each project must demonstrate a return on investment (RoI) of at least 100 % of the funding amount no later than 3 years after the end of the project.

The "Multi-Med" project is a preparatory project funded by the FhG with the aim of improving diagnostics in cancer detection and therapy and will run from 06/2023 – 05/2026. Under the leadership of Fraunhofer EMI, Fraunhofer MEVIS and Fraunhofer FHR are also involved.

PREPARE-Project »Multi-Med«
victoria.heusinger-hess@emi.fraunhofer.de

Photo: Gorodenkoff / stock.adobe.com

Institute overview

Administration, personnel, publications at a glance

← **Apprenticeship at Fraunhofer EMI**
Precision mechanics, electronics, media design, and dual studies: EMI offers numerous training opportunities. Currently 21 people are being trained.

Photos: Fraunhofer EMI (2)

The institute in figures

395
Employees

- 40 % Scientific staff in specialist departments
- 13 % Non-scientific staff in specialist departments
- 26 % Management and infrastructure
- 16 % Hiwi, interns
- 5 % Trainees, DHBW students

Total personnel all locations

Personnel by location

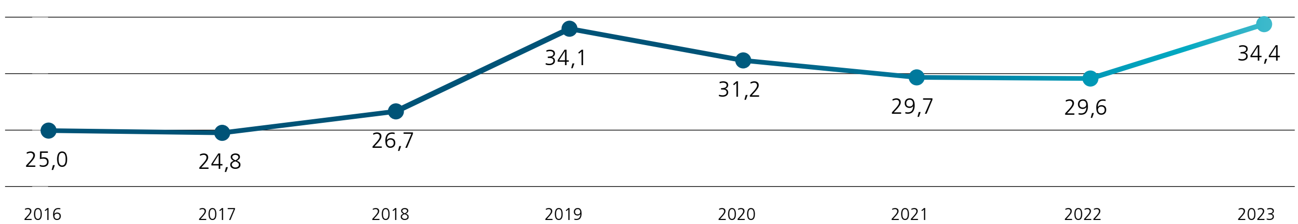
222 Freiburg	130 Efringen-Kirchen	32 Kandern	11 Berlin

5 business units: Defense, Security & Resilience, Automotive, Space, Aviation

Finances

34.4	18.4	95
million total budget	million external funding	externally funded projects (as at 31.3.24)

Total budget in € million



Science

101	57	38
Publications with peer review	Lectures	Courses

5	2	34
Patents	Doctorates	Bachelor's and Master's theses

Scientific cooperation

- University of Freiburg
- University of Oxford
- NTU Singapore
- Cranfield University
- MIT
- Cluster Micro TEC Südwest
- Centre for Security
- Cluster Electric Mobility South-West

Personnel

At the end of 2023, a total of 395 people were employed at Fraunhofer EMI: 310 permanent staff, 21 trainees and DHBW students and 64 research assistants and interns. Of the permanent staff, 204 worked directly in research and 106 in management and infrastructure.

The proportion of female permanent staff was 25.8 %. Of the permanent staff, 56.1 % were employed at the Freiburg site, 32.9 % at the Efringen-Kirchen site, 8.1 % at the Kandern site and 2.9 percent at the Berlin site.

Of the total of 21 trainees, 13 were employed in the fields of precision mechanics, electronics and media design. 8 employees were employed at Fraunhofer EMI for the purpose of their vocational training or as part of their studies at the Baden-Württemberg Cooperative State University.

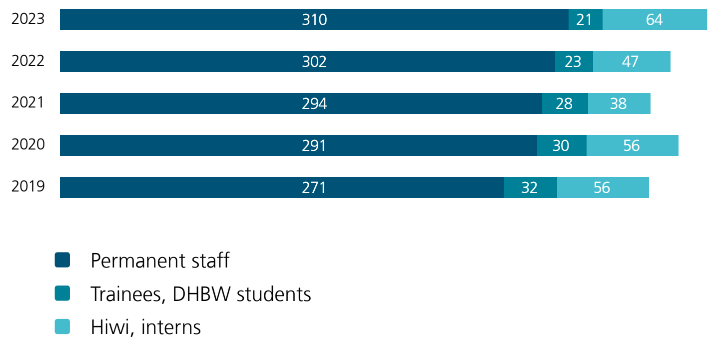
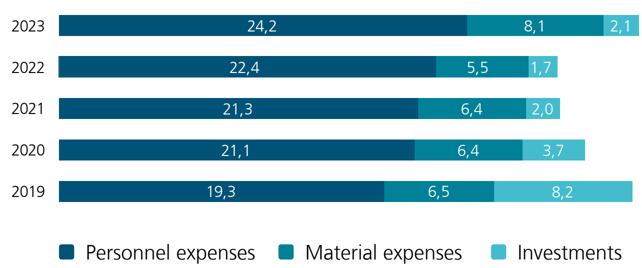


Photo: Fraunhofer EMI

Finances

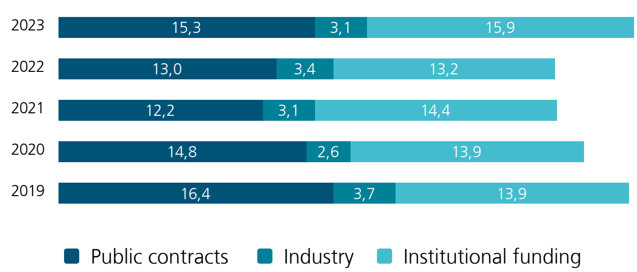
Total budget expenditure

in millions of euros

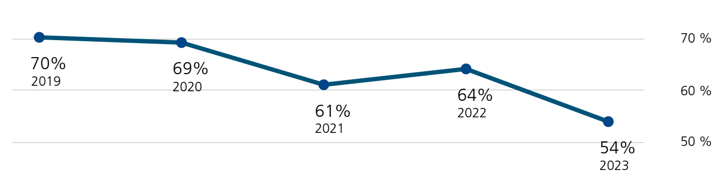


Total budget revenue

in millions of euros



The total budget of Fraunhofer EMI increased by 16 % compared to the previous year (from 29.6 to 34.4 million euros). The operating budget has also risen (from 27.9 to 32.2 million euros). There was also an increase in EU income. This has risen from 0.9 million to 1.2 million euros. There was also an increase in the civilian share. The share of BMVg funding amounts to 54 % (previous year: 64 %).



BMVg share in relation to the total budget, in percent.

Advisory board

The Advisory board supports the institute's management in an advisory capacity. It promotes the institute's contacts with organizations and with industry.

Hanna Böhme
Managing Director Freiburg Wirtschaft Touristik und Messe GmbH & Co. KG, FWTM, Freiburg

Dipl.-Ing. Thomas Gottschild (Chairman)
Managing Director MBDA Deutschland GmbH, Schrobenhausen

Ministerialrätin Sabine ten Hagen-Knauer
Head of Division 524: Civil Security research, German Federal Ministry of Education and Research (BMBF), Bonn

Rainer Hoffmann
CEO carhs.training GmbH, Alzenau

Univ.-Prof.in Dr.-Ing. habil. Dr. mont. Eva-Maria Kern
President University of the Bundeswehr Munich, Neubiberg

Ministerialrat Dipl.-Phys. Claus Mayer
Head of Division 33: Automotive and Manufacturing Industries, Logistics, State Ministry of Economic Affairs, Labour and Tourism, Baden-Württemberg, Stuttgart

Brigadier General Michael Meinl
Director French-German Research Institute Saint-Louis ISL, Binzen

Michael Schätzle
Vice President Product Line Cayenne, Porsche AG, Weissach

Brigadier General Jürgen Schmidt
Head of Combat Division, Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support (BAAINBw), Koblenz

Dr. Tobias Schmidt
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In the painting: Fraunhofer demonstrates his spectrometer (standing, with black coat).

Photos: Fraunhofer EMI, Fraunhofer-Gesellschaft

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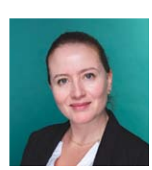

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Publications, lectures, scientific exchange

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Publications (with peer review)

Albert, K.; Krivova, N. A.; Hirzberger, J.; Solanki, S. K.; Moreno Vacas, A.; Orozco Suárez, D. et al. (2023): **Intensity contrast of solar network and faculae close to the solar limb, observed from two vantage points.** In: Astronomy & Astrophysics 678, A163. DOI: 10.1051/0004-6361/202346037.

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Bauer, S. (2023): **Modellbildung für transparente Schutzwerkstoffe – Quantitative Modellbildung zur Materialvorschädigung durch dem Projektil vorauslaufende mechanische Wellen.** EMI-Symposium 2023, 06.12.2023.

Burtsche, J. (2023): **Charakterisierung der Schädigung von Beton im Rahmen meines DH-Studiums.** EMI-Hausseminar. Freiburg, 27.04.2023.

Durr, N. (2023): **Dynamic loading of concrete and other geomaterials.** EMI MD-CUBE, 12.07.2023.

Fischer, K. (2023): **Datengetriebene kommunale Resilienzbewertung in Bezug auf Extremwetter und Pandemie – Übersicht des BMBF-Projekts HERAKLION.** EMI-Hausseminar, 20.07.2023.

Fischer, K. (2023): **Datengetriebene kommunale Resilienzbewertung in Bezug auf Extremwetter und Pandemie – Übersicht des BMBF-Projekts HERAKLION.** SIRIOS Fachgespräche. Berlin, 29.08.2023.

Heine, A. (2023): **Wirkmechanismen zur Abwehr hypersonischer Bedrohungen – Neue Herausforderungen infolge nicht-ballistischer Flugbahnen.** EMI-Symposium 2023 »Forschung im Dialog: Wirkung und Schutz«. EMI Freiburg, 06.12.2023.

Holz, S. (2023): **Ausgewogener Nuklearschutz - Simulationsmodelle für die Wirkungsanteile Blast und Hitzeblitz auf Gefechtsfahrzeuge.** EMI-Symposium 2023, 07.12.2023.

Holz, S.; Schaufelberger, B. (2023): **Batteriesicherheit in der Luftfahrt.** EMI-Hausseminar, 30.03.2023.

Jung, M. (2023): **FastTrack-Projekt 3Druckverschluss: 3D-gedruckte reversible Metall-Faserverbund-Verbindungen.** EMI-Hausseminar. EMI Freiburg, 23.10.2023.

Lüttner, F.: **Verkehrssimulationsmodell als Grundlage für die Prognose von Verkehrsunfallstatistiken im zukünftigen Verkehrsgeschehen.** EMI-Doktorandenseminar. Freiburg.

Matura, P.; Osterholz, J. (2023): **Trägheit als Tugend: Kernfusionsforschung und Beitragsmöglichkeiten des EMI.** EMI-Hausseminar, 30.03.2023.

Matura, P.; Signetti, S.; Moser, S.; Sandoval, L.; Durr, N.; Watson, E. et al. (2023): **Beitrag zur Kernfusionsforschung – Den Folgen von Plasmastörungen in Kernfusionsreaktoren entgegenwirken: Anwendung der EMI-Kompetenzen zu Fragmentierungsmodellen.** EMI-Symposium 2023, 06.12.2023.

May, M. (2023): **Drohnenimpakt – Erweiterte Anforderungen an die sichere Auslegung von Flugzeugen und Hubschraubern.** EMI-Symposium 2023. EMI Freiburg, 06.12.2023.

Niklas, W. (2023): **Aktuelle Arbeiten zur softwarebasierten Sicherheitsanalyse beim Freifeld-Einsatz.** HEL-Institutstreffen. EMI Freiburg, 24.01.2023.

Reich, S. (2023): **High-throughput-Laserhärten von Stahl mit dem 120 kW-Laser.** EMI-Hausseminar, 25.05.2023.

Rietkerk, R. (2023): **Anwendung der Methoden künstlicher Intelligenz für Wirkung und Schutz – Maschinelles Lernen für die Ableitung von Modellparametern dynamischer Werkstoffmodelle.** EMI-Symposium 2023 »Forschung im Dialog: Wirkung und Schutz«. EMI Freiburg, 06.12.2023.

Rietkerk, R. (2023): **Maschinelles Lernen für die Ableitung von Modellparametern dynamischer Werkstoffmodelle.** EMI-Hausseminar. Efringen-Kirchen, 30.11.2023.

Rietkerk, R. (2023): **Anwendung der Methoden künstlicher Intelligenz für Wirkung und Schutz – Maschinelles Lernen für die Ableitung von Modellparametern dynamischer Werkstoffmodelle.** EMI-Symposium 2023. Freiburg, 06.12.2023.

Rosin, J.; Delleske, C.; Lüttner, F. (2023): **GUARDIAN – gathered sensor unit for automatic and rapid detection of human infrared signature in acute need.** EMI-Hausseminar. EMI Freiburg, 26.01.2023.

Ruiz-Ripoll, M. A.; Thielen, M. (2023): **Aktuelle Forschungsthemen rund um innovativen Beton: Kryogener Beton und 3D-gedruckter Beton.** EMI-Hausseminar, 25.10.2023.

Sättler, A.; Aurich, H. (2023): **Wirkmechanismen und Zielannäherung – Anforderungen an zukünftige Gefechtsköpfe zur Wirkung gegen gepanzerte Landplattformen.** EMI-Symposium 2023 "Forschung im Dialog: Wirkung und Schutz". EMI Freiburg, 07.12.2023.

Soot, T. (2023): **"Grey-Box-Processing" - Integrales Validierungsverfahren für Struktursimulationen in der Fahrzeugsicherheit.** 49. Kuratoriumssitzung des Fraunhofer-Institut für Kurzzeitdynamik Ernst-Mach-Institut, EMI. EMI Freiburg, 07.07.2023.

Soot, T. (2023): **"Grey-Box-Processing" - Neuartiger Verfahrensansatz zur Validierung von kurzzeitdynamischen Simulationen am Beispiel Fahrzeugcrash.** EMI-Symposium 2023, 07.12.2023.

Vetter, J.; Rosin, J. (2023): **SIRIOS Pilotprojekt 1: SchIRm – Strategien zum Schutz kritischer Infrastrukturen bei umweltverursachten Gefährdungslagen in urbanen Räumen.** EMI-Hausseminar. EMI Freiburg, 26.04.2023.

Courses of the Carl Cranz Society

Straßburger, E. (2023): **Endballistik kleinkalibriger Geschosse – Keramik für den ballistischen Schutz.** Seminar VS 1.43 "Endballistik – Grundlagen und Anwendungen". Saint Louis, 20.06.2023.

Teaching

Lectures

Asa, P.; Neuhäuser, S. (Wintersemester 2023/2024): **Digital and Analogue Formfinding and Optimization.** TU Berlin.

Balle, F. (Sommersemester 2023): **Drahtbonding auf Micro-CPV-Modulen - Untersuchung verschiedener Materialien für die Oberflächenkontaktierung.** Vorlesung. Albert-Ludwigs-Universität Freiburg.

Balle, F. (Wintersemester 2023/2024): **Lightweight Design and Materials.** Vorlesung. Albert-Ludwigs-Universität Freiburg.

Balle, F. (Wintersemester 2023/2024): **Materials Selection for Sustainable Engineering.** Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg.

Balle, F. (Sommersemester 2023): **Nachhaltige Materialien.** Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg.

Balle, F. (Sommersemester 2023): **Technische Funktionswerkstoffe.** Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg.

Balle, F. (Wintersemester 2023/2024): **Werkstofftechnik und -prozesse.** Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg.

Balle, F.; Hiermaier, S.; Kilchert, S. (Sommersemester 2023): **SSE-Studienseminar.** Albert-Ludwigs-Universität Freiburg.

Häring, I. (Sommersemester 2023): **Funktionale Sicherheit - Aktive Resilienz / Functional Safety: Active Resilience.** Vorlesung. Albert-Ludwigs-Universität Freiburg.

Häring, I. (Sommersemester 2023): **Quantitative Risikoanalyse.** Hochschule Furtwangen.

Häring, I. (Wintersemester 2023/2024): **Resilienzquantifizierung / Quantification of Resilience.** Vorlesung. Albert-Ludwigs-Universität Freiburg.

Häring, I. (Wintersemester 2023/2024): **Risk and Resilience Analysis.** Hochschule Furtwangen.

Harwick, W. (Wintersemester 2023/2024): **Werkstoffe.** Vorlesung. DHBW Lörrach.

Hiermaier, S. (Sommersemester 2023): **Climate Change.** Vorlesung. Albert-Ludwigs-Universität Freiburg.

Hiermaier, S. (Sommersemester 2023): **Grundlagen resilienter Systeme.** Vorlesung. Albert-Ludwigs-Universität Freiburg.

Hiermaier, S. (Sommersemester 2023): **Resilienz im Brand- und Katastrophenschutz faßbar machen.** Darstellung von Anknüpfungspunkten in Resilienzkonzepte in Prävention, Aufklärung und Führung. Vorlesung. Albert-Ludwigs-Universität Freiburg.

Hiermaier, S.; Ganzenmüller, G. (Sommersemester 2023): **Angewandte Finite Elemente für die Strukturmechanik.** Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg.

Hiermaier, S.; Ganzenmüller, G. (Wintersemester 2023/2024): **Grundlagen der mechanischen Werkstoffcharakterisierung / Basics of mechancial testing.** Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg.

Hiermaier, S.; Ganzenmüller, G. (Wintersemester 2023/2024): **Physics of Failure.** Vorlesung. Albert-Ludwigs-Universität Freiburg.

Hiermaier, S.; Ganzenmüller, G. (Sommersemester 2023): **Werkstoffdynamik: Werkstoffcharakterisierung / Dynamics of Materials: Material Characterization.** Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg.

Hiermaier, S.; Ganzenmüller, G.; Schroven, K. (Wintersemester 2023/2024): **Fundamentals of Resilience.** Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg.

Hiermaier, S.; Kilchert, S. (Wintersemester 2023/2024): **Lebenszyklusanalyse.** Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg.

Hiermaier, S.; Kilchert, S. (Sommersemester 2023): **Material Flow Analysis.** Vorlesung. Albert-Ludwigs-Universität Freiburg.

Hiermaier, S.; Kilchert, S.; Ganzenmüller, G. (Wintersemester 2023/2024): **Material Life Cycles.** Albert-Ludwigs-Universität Freiburg.

Hiermaier, S.; Matura, P. (Wintersemester 2023/2024): **Kontinuumsmechanik.** Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg.

Imbert, M.; May, M.: **Composite Materials.** Vorlesung. Wintersemester 2023/2024. Albert-Ludwigs-Universität Freiburg.

Lickert, B. (Sommersemester 2023): **Resilience of Supply Networks.** Übung. Albert-Ludwigs-Universität Freiburg.

Matura, P. (Sommersemester 2023): **Numerische Methoden in der Mathematik.** Vorlesung. DHBW Lörrach.

Osterholz, J. (Sommersemester 2023): **High-Energy-Density Physics.** Vorlesung. Heinrich-Heine-Universität Düsseldorf.

Ramin, M. von (Sommersemester 2023): **Lehrbeauftragter im Masterstudiengang Katastrophenvorsorge und -Management, Unterrichtseinheit 4 “Bauliche Prävention im Bevölkerungsschutz” im Modul 5: “Ausgewählte Konzepte und Maßnahmen der Katastrophenvorsorge”.** Rheinische Friedrich-Wilhelms-Universität Bonn.

Riedel, W. (Sommersemester 2023): **Schutz baulicher Infrastrukturen.** Hochschule Furtwangen.

Sauer, M. (Wintertrimester 2023 und 2024): **Laborpraktikum.** Universität der Bundeswehr München.

Sauer, M. (Wintertrimester 2023 und 2024): **Numerische Simulationsverfahren.** Vorlesung. Universität der Bundeswehr München.

Sauer, M. (Wintertrimester 2023 und 2024): **Werkstoffcharakterisierung.** Vorlesung. Universität der Bundeswehr München.

Stolz, A. (Sommersemester 2023): **Design and Monitoring of Large Urban Infrastructures.** Vorlesung. Albert-Ludwigs-Universität Freiburg.

Stolz, A. (Wintersemester 2023/2024): **Structural Robustness: Resilient Designs.** Vorlesung. Albert-Ludwigs-Universität Freiburg.

Stolz, A. (Wintersemester 2023/2024): **Strukturelle Sicherheit.** Albert-Ludwigs-Universität Freiburg.

Stolz, A.; Lickert, B. (Sommersemester 2023): **Resilience of Supply Networks.** Vorlesung und Übung. Albert-Ludwigs-Universität Freiburg.

Visiting scientists

Dr. Iaci Miranda Pereira aus dem Brazilian Army Technological Center vom 1.3.2023 bis zum 30.6.2023.

Doctorates

Grunwald, C. (2023): **Numerische Modellierung der Fragmentierung von Beton unter kurzzeitdynamischer Belastung mit Hilfe einer Zwei-Skalen-Kopplung.** Dissertation. Albert-Ludwigs-Universität Freiburg.

Holz, S. (2023): **Multivariate Statistische Modellierung der Tropfenstartbedingungen für Euler-Lagrange-Simulationen von Triebwerksbrennkammern.** Dissertation. Karlsruher Instituts für Technologie (KIT).

Bachelor's and Master's theses

Burtsche, J. (2024): **Simulationsbasierte Analysen zur Ableitung von Ingenieurmodellen für die Starrkörperpenetration in ultrahochfesten Beton.** Masterarbeit. EMI-Bericht A 02/24. Hochschule Offenburg.

Denli, B. (2023): **Innovative design for the recycling for composites.** Master Thesis. EMI-Report A 35/23. Albert-Ludwigs-Universität Freiburg.

Dhanani, M. (2023): **Failure and Recovery Models of Autonomous vehicles subsystems for Markov safety simulation.** Master Thesis. EMI-Report A 20/23. Hochschule Nordhausen.

Dommershausen, T. (2023): **Numerische Betrachtung des Druckverlustes einer stationären, inkompressiblen Strömung durch ein granulares Medium.** Bachelorarbeit. EMI-Bericht A 41/23. DHBW Mannheim.

Ekbote, N. (2023): **Impact behavior of a carbon fiber reinforced polymer featuring thin-ply with an innovative bio-inspired helicoidal layup.** Master Thesis. EMI-Report A 43/23. Ernst-Abbe-Hochschule Jena.

Guillen, F. M. (2023): **Data-driven material models – quantification of strain information content in characterization tests.** Master Thesis. EMI-Report A 38/23. Albert-Ludwigs-Universität Freiburg.

Gutt, F. (2023): **A knowledge-graph-based approach for modeling interdependencies discovered using statistical methods on heterogenous and decentralized data for quantitative resilience analysis.** Bachelor Thesis. EMI-Report A 11/23. Albert-Ludwigs-Universität Freiburg.

Haridy, A. (2023): **Resilience evaluation of power grids using synchronizing network models.** Master Thesis. EMI-Report A 10/23. Albert-Ludwigs-Universität Freiburg.

Heitz, M. (2023): **Entwicklung einer Hochgeschwindigkeits-CT mit einem 1-kHz-Linearbeschleuniger.** Masterarbeit. EMI-Bericht A 12/23. DHBW Center for Advanced Studies.

Hilfer, E.-J. (2023): **Untersuchung 3D-gedruckter Kunststoffe hinsichtlich des mechanischen Verhaltens.** Masterarbeit. EMI-Bericht A 09/23. Hochschule Albstadt-Sigmaringen.

Huber, J. (2023): **Development and integration of variable design spaces in the topology optimization process.** Master Thesis. EMI-Report A 21/23. Hochschule Karlsruhe.

Jansen, N. (2023): **Aufbau eines Messsystem-Kanals für Photonic-Doppler-Velocimetry (PDV) mittels moderner Fertigungsverfahren.** Bachelorarbeit. EMI-Bericht A 28/23. DHBW Mannheim.

Jasper, L. (2023): **Analyse zur Automatisierung von Werkstoffversuchen zur Gewinnung großer Datenmengen für die Anwendung von datenbasierten Methoden in der Werkstoffmodellierung.** Bachelorarbeit. EMI-Bericht A 29/23. DHBW Mannheim.

Jehle, S. (2023): **Assessment of façade greening systems performance under blast loads.** Master Thesis. EMI-Report A 24/23. Hochschule Furtwangen.

Köhler, H. (2023): **Low power implementation of an ultrasonic communication system through metal.** Master Thesis. EMI-Report A 23/23. Albert-Ludwigs-Universität Freiburg.

Laerum, P. (2023): **Agentenbasierte Modellierung der Interaktion zwischen Einsatzkräften mit Personenmengen während Großveranstaltungen.** Masterarbeit. EMI-Bericht A 39/23. Hochschule Furtwangen.

Luna Mejia, M. J. (2023): **Hypervisor evaluation for virtualization of a high-performance small satellite payload.** Master Thesis. EMI-Report A 08/23. Albert-Ludwigs-Universität Freiburg.

Mopuru, S. K. R. (2023): **Safety analysis of autonomous driving by Markov modelling with a focus on hardware architectures.** Master Thesis. EMI-Report A 01/23. Hochschule Bremerhaven.

Moser, A. (2023): **Indikatorbasierte Charakterisierung kommunaler Resilienz als Hilfsmittel zur Bewertung der Krisenfestigkeit.** Bachelorarbeit. EMI-Bericht A 26/23. Albert-Ludwigs-Universität Freiburg.

Müller, D. (2023): **Entwurf und Konstruktion von modellhaften Steuereinheiten von Lenkflugkörpern für Laserbeschussversuche.** Bachelorarbeit. EMI-Bericht V 09/23. DHBW Mannheim.

Omprakash, A. S. (2023): **AI based analysis of radar data for the identification of vital signs of life.** Master Thesis. EMI-Report A 44/23. Universität Siegen.

Padariya, R. (2024): **Failure rate estimation of lane detection from CARLA Simulation for Markov Model safety assessment of autonomous driving functions.** Master Thesis. EMI Report A 01/24. Westsächsische Hochschule Zwickau.

Prajapati, B. (2023): **A comparative study of crack volume segmentation methods for dynamically damaged glass and ceramics.** Master Thesis. EMI-Report A 07/23. Leibniz-Universität Hannover.

Rinnert, T. (2023): **Calibration of an agent-based-simulation for vulnerable road user behavior on street crossings.** Master Thesis. EMI-Report A 22/23. Georg-August-Universität Göttingen.

Sandela, N. (2023): **Safety and reliability analysis of autonomous driving using Markov modeling and Deep Learning.** Master Thesis. EMI-Report A 19/23. Otto-von-Guericke-Universität Magdeburg.

Savsani, M. (2023): **Numerical analysis of the structural deformation and failure of Lithium-ion pouch cell during thermal runaway.** Master Thesis. EMI-Report A 42/23. Universität Rostock.

Schuster, P. (2023): **Basic software of a monitoring and reconfiguration module for nanosatellites.** Bachelor Thesis. Graz University of Technology.

Selbiger, J. (2023): **Weiterentwicklung von dynamischen Zugund Druckprüfungen hin zu kombinierter thermischer und dynamischer Belastung.** Masterarbeit. EMI-Bericht A 06/23. Universität Stuttgart.

Singler, M. (2023): **Semantische Segmentierung von Rissen mittels Deep Learning in Computertomographie-Scans von Glas- und Keramikproben.** Masterarbeit. EMI-Bericht A 02/23. Albert-Ludwigs-Universität Freiburg.

Subrahmanya, S. (2023): **Finite Element Analysis of Hydrodynamic RAM (HRAM) effect due to high-speed projectile impact on a stationary tank filled with fluid.** Master Thesis. EMI-Report A 30/23. Albert-Ludwigs-Universität Freiburg.

Vayakara, M. (2023): **Criticality measures for driving scenarios of robot cars.** Master Thesis. EMI-Report A 04/23. Technische Hochschule Deggendorf.

Walter, J. (2023): **Simulation multimodaler Logistikketten unter Störeinflüssen und Nachhaltigkeitsaspekten.** Bachelorarbeit. EMI-Bericht A 25/23. DHBW Lörrach.

Weber, N. (2023): **Untersuchung von Einflussfaktoren auf den Gehalt an Restaustenit in additiv gefertigtem 17-4PH-Stahl.** Bachelorarbeit. EMI-Bericht A 27/23. DHBW Lörrach.

Zhou, J. (2023): **Konzeption und Bemessung einer Split- Hopkinson-Bar-Anlage zur Charakterisierung kunststoffgebundener Sprengladungen.** Bachelorarbeit. EMI-Bericht A 33/23. DHBW Mannheim.

Patents, prizes, excellence in research

Patents

Früh, P. (2020): **Geschoßanordnung und deren Verwendung am 01.07.2020.** Veröffentlichungsnr: DE 10 2020 005 592.

Lüttner, F. (2023): **Method and apparatus for indicating the presence of a buried person in a building after a collapse of the building.** Veröffentlichungsnr: 11,545,020.

Rosin, J.; Delleske, C.; Lüttner, F. (2023): **Method and apparatus for indicating the presence of a buried person in a building after a collapse of the building.** Veröffentlichungsnr: US11545020B2.

Rosin, J.; Delleske, C.; Lüttner, F. (2023): **Method and apparatus for indication the presence of a buried person in a building after a collapse of the building.** Veröffentlichungsnr: EP4036885A1.

Solass, J.; Köpke, C. (2023): **System and method for determining the mass of a ship moving in water.** Veröffentlichungsnr: EP4232357A1.

Prizes and awards

Fischer, G. K. J.: **Best Paper Award für "A Measurement Platform for the Evaluation of Sparse Acoustic Array Geometries"** auf der International Conference on Indoor Positioning and Indoor Navigation (IPIN), IPIN 2023.

Horch, C.: **Fraunhofer-Preis "Technik für den Menschen und seine Umwelt" 2023.** Thema "Wasser effizienter nutzen: Neue Satellitentechnologie ermöglicht nachhaltige Landwirtschaft in Zeiten des Klimawandels".

May, M.: **Stanford University "World's Top 2% Scientists",** Kategorie: Impact of the last year.

May, M.: **Stanford University "World's Top 2% Scientists",** Kategorie: Career-long.

Reich, S.: **The Best Rapid-Fire Presentation at Frontiers in Optics 2023.**

Riedel, W.: **Stanford University "World's Top 2% Scientists",** Kategorie: Impact of the last year.

Schäfer, F.: **Stanford University "World's Top 2% Scientists",** Kategorie: Career-long.

Evaluated excellence research

BMBF KMU Innovativ Beep2Blue.

BMBF-Förderung für Fraunhofer SIRIOS.

BMBF-Verbundvorhaben "Handwaffen mit selbstgedruckten Teilen – eine Risikoabschätzung (HamsTeR)"

BMWi LoCA.

BMWi RDV.

LOKI-PED — Lithium Batteries Fire/Smoke Risks in Cabin.

EU-Programm "Clean Aviation". Projekt "Ultra Performance Wing".

Projekt RESIST.

Participation in specialist committees

Fischer, K.: Projektbeirat "Stresstest für Städte", Bundesamt für Bauwesen und Raumordnung (BBR).

Häring, I.: Co-Editor European Journal for Security Research, EJSR.

Heine, A.: Editorial Advisory Board, International Journal of Impact Engineering.

Heine, A.: Scientific Committee, Light-Weight Armour for Defence & Security, LWAG 2024, Rocamadour, France, June 10-13, 2024.

Heine, A.; Signetti, S.: Organizing Committee, 4th International Conference on Impact Loading of Structures and Materials, ICILSM 2024, Freiburg, Germany, May 13-17, 2024.

Köpke, C.: Member of the Programm Committee of the 4th International Workshop on Cyber-Physical Security for Critical Infrastructures Protection (CPS4CIP 2023) of ESORICS 2023.

Köpke, C.: Mitglied in der Young Academy for Sustainabilty Research an der Universität Freiburg, FRIAS.

May, M.: AIAA International Activities Advisory Committee.

May, M.: AIAA International Honor and Awards Development Committee.

May, M.: Fraunhofer Program Management Team Clean Aviation.

May, M.: Governing Board Clean Aviation.

May, M.: Program Management Committee Member Fraunhofer Clean Sky 2 Airframe.

May, M.: Scientific Committee Composites 2023 Conference, Trapani, Italien, 12.-14. September 2023.

May, M.: Stellv. Sprecher Fraunhofer VVS für FACT.

May, M.: Stellv. Steering Committee Member Fraunhofer Clean Sky 2 Airframe.

Meyer, R.: Mitglied Programmkomitee der Social Simulation Conference (SSC 2023).

Meyer, R.: Mitglied Programmkomitee des 24. International Workshop on Multi-Agent-Based Simulation (MABS 2023).

Putzar, R.: Repräsentant des Fraunhofer Ernst-Mach-Instituts in der Aeroballistic Range Association (ARA).

Ramin, M. von: Deutscher Delegierter für die NATO PFP(AC/326-SG/C) AASTP-4 Custodian Working Group.

Ramin, M. von: Mitarbeit in der Klotz Group.

Ramin, M. von: Mitglied im Editorial Board "International Journal of Protective Structures".

Ramin, M. von: Mitglied in der "European Commission expert group 'Fighting Crime and Terrorism, including Resilient Infrastructure' for the Community for European Research and Innovation for Security (CERIS)".

Ramin, M. von: Mitglied in der Deutschen Gesellschaft für Erdbebeningenieurwesen und Baudynamik, DGEB.

Rosin, J.: Mitglied der DGEB – Deutsche Gesellschaft für Erdbebeningenieurwesen und Baudynamik e.V.

Rosin, J.: Mitglied im Normenausschuss NA 104 DIN Standards Committee Tank Installations (NATank) Deutscher Spiegelausschuss CEN/TC 265/WG 10.

Rosin, J.: Projektleitung im Normenausschuss, CEN/TC 265/WG 10 – Revision of EN 14620 Design and manufacture of site built, vertical, cylindrical, flat-bottomed steel tanks for the storage of refrigerated, liquefied gases with operating temperatures between 0 °C and -165 °C.

Rößner, S.: Fraunhofer Representative im Steering Committee von Clean Sky 2 ITD Airframe.

Rößner, S.: Mitglied im Advisory Council for Aviation Research and Innovation (ACARE), WG 4 Safety & Security.

Ruiz-Ripoll, M. A.: Mitglied bei der European Structural Integrity Society (ESIS).

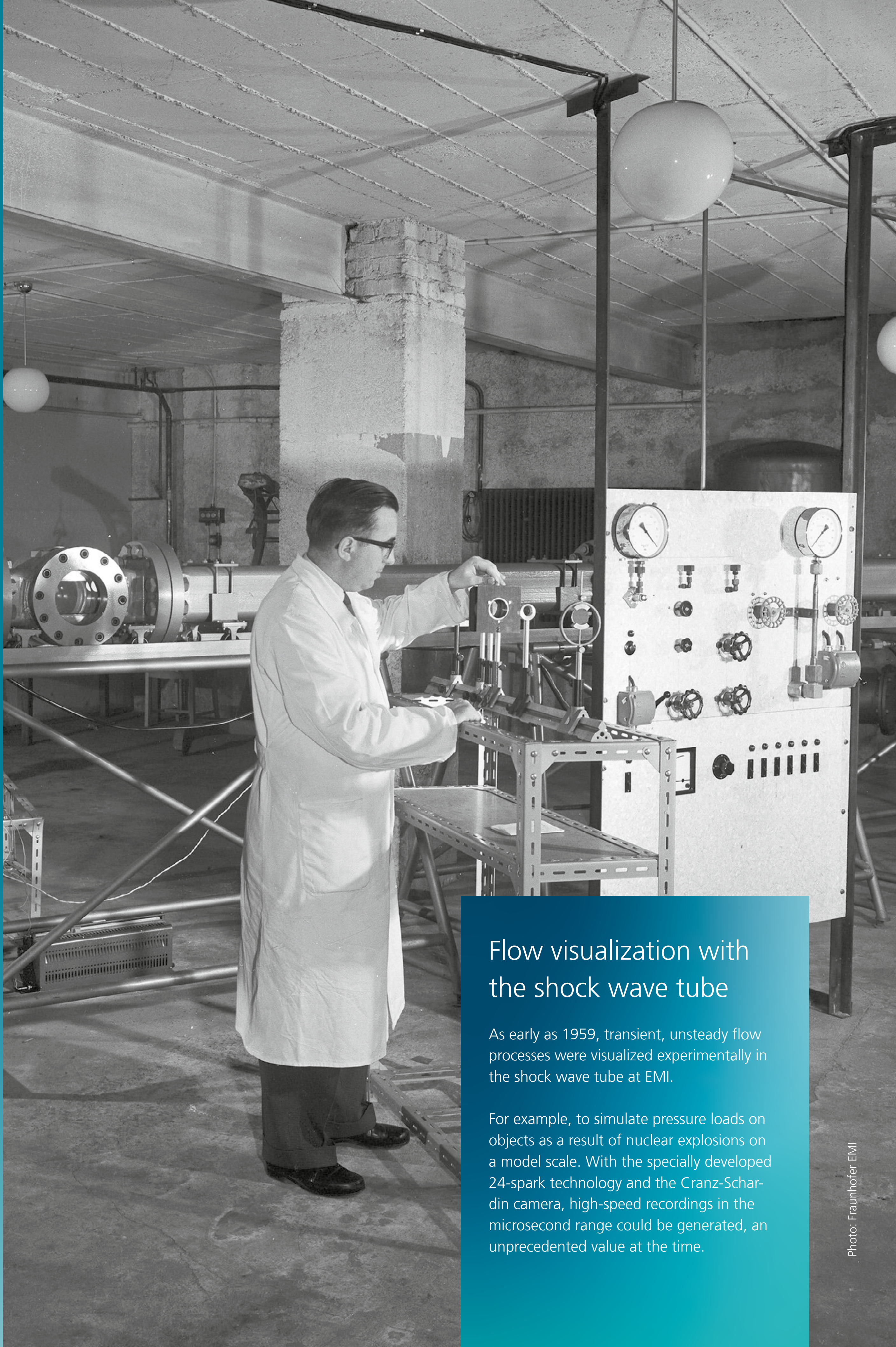
Ruiz-Ripoll, M. A.: Mitglied beim Grupo Español de Fractura (GEF).

Sättler, A.: Mitglied im Arbeitskreis Innenballistik der Rohrwaffen.

Stocchi, A.: Mitglied der fib – Fédération Internationale du Béton (International Federation for Structural Concrete).

Stolz, A.: Mitglied des Transport Research Boards (TRB) im AMR 10 Standing Committee on Critical Transportation Infrastructure Protection.

Stolz, A.: Mitglied DGEB – Deutsche Gesellschaft für erdbebeningenieurwesen und Baudynamik.



Flow visualization with the shock wave tube

As early as 1959, transient, unsteady flow processes were visualized experimentally in the shock wave tube at EMI.

For example, to simulate pressure loads on objects as a result of nuclear explosions on a model scale. With the specially developed 24-spark technology and the Cranz-Schardin camera, high-speed recordings in the microsecond range could be generated, an unprecedented value at the time.

Photo: Fraunhofer EMI

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